Relationship of indoor particulate matter and lung function in children from the Eastern Cape Province of South Africa

G A Engwa,[1] PhD; **C Anye**,[2] PhD; **B N Nkeh-Chungag**,[1] MPH, PhD

[1] *Department of Biological and Environmental Sciences, Faculty of Natural Sciences, Walter Sisulu University, Mthatha, South Africa*
[2] *Dayenuel Consulting, Mthatha, South Africa*

Corresponding author: *B N Nkeh-Chungag (bnkehchungag@wsu.ac.za)*

Background. There is a dearth of information on the relationship between indoor air pollution and lung function, especially among sub-Saharan African children.
Objective. To assess the relationship between indoor particulate matter (PM) and lung function in children living in the Eastern Cape Province of South Africa (SA).
Methods. This cross-sectional study included 540 children aged 10 - 14 years and was conducted between May and September 2016. PM from 23 classrooms was measured with a handheld particle counter and lung function was assessed with a handheld spirometer.
Results. Mean (standard deviation) PM_5 levels were higher (109.96 (75.39) µg/m^3) than PM_{10} (84.84 (63.28) µg/m^3) and $PM_{2.5}$ (39.45 (26.38) µg/m^3). $PM_{2.5}$, PM_5 and PM_{10} correlated negatively (p<0.05) with forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), FEV_{25-75}, as well as peak expiratory flow (PEF) but correlated positively (p<0.001) with the FEV_1/FVC ratio.
Conclusion. PM in classrooms showed a negative relationship with lung function in the study population.

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Particulate matter (PM) air pollution is a leading cause of morbidity and mortality globally. In 2017, ambient $PM_{2.5}$ was reportedly responsible for 2.9 million premature deaths globally[1] and was the fifth mortality risk factor responsible for 103.1 million disability-adjusted life-years in 2015.[2] PM constitutes extremely small coarse/fine particles (PM_{10} - $PM_{2.5}$), which include liquid droplets or dust containing soil, metals, acids or organic compounds varying in width from 2.5 to 10.0 µm. They are of health importance as they can be inhaled by humans and deposited in the lungs, specifically in the alveoli, where they gain access to the circulation.

Lung function tests are often used as indicators to assess the effects of air pollution on the lungs. A meta-analysis of the European Study of Cohorts for Air Pollution Effects (ESCAPE) in adults showed that an increase in PM_{10} levels was found to be associated with lower values for forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC).[3] Some studies have shown an association between PM exposure-related lung diseases, including coughing, irritation of the airways, breathing difficulty, asthma and chronic obstructive pulmonary disease.[4]

Children are believed to be particularly vulnerable to the health consequences of PM exposure because of their high ventilation rates. Consequently, they tend to inhale more PM per minute than adults in the same environment. Importantly, confined spaces such as classrooms with active children increase the risk of exposure to air pollution. This is supported by reports which suggest that indoor air pollution owing to air stagnation is considered a greater health hazard than outdoor air pollution. Although many studies in Western and Asian populations have reported on the relationship between indoor air quality and lung function in children, there is limited information on African children. Hence, the present study assessed the relationship between PM and lung function in children in the Eastern Cape Province of South Africa (SA).

Methods

Study design

We conducted a cross-sectional study involving 540 children (250 males and 290 females) aged 10 - 14 years who were recruited from 7 middle schools in the Eastern Cape Province, South Africa (SA) from May to September 2016. Children who were free from any evident or reported pulmonary and chronic cardiovascular diseases, were recruited for the study. Children with fever or disability as well as individuals on antihypertensive medication were excluded from the study.

Ethics approval was obtained from the Health Sciences Ethics Committee of Walter Sisulu University (ref. no. 112/2018). Participation was voluntary and written informed consent was obtained from the relevant school authorities and parents/legal guardians before enrolment into the study. Participants' data were stored anonymously.

Particulate matter count

PM from 23 classrooms was measured with a handheld particle counter (Met-One-Model-804; Met One Instruments Inc., USA) as per the manufacturer's protocol. The device was placed at a height of 60 cm above the floor in the centre of each classroom. Two continuous measurements of $PM_{2.5}$, PM_5 and PM_{10} were automatically recorded by the device for 15 minutes between 8h00 and 13h00 when learners were in the classrooms. The average of two readings was determined and expressed in µg/m^3. Measurements were done at relatively normal humidity (30 - 50%).

Pulmonary function tests

Lung function assessment was done in accordance with American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines[5] using a Contec handheld spirometer (SP10 model; Contec Medical Systems Co., China) as per the manufacturer's protocol. All respiratory volumes and ratios were automatically recorded by the device and repeated at least four times. The best of three technically acceptable values for forced expiratory volume in 1 second (FEV_1), forced expiratory volume 25 - 75% interquartile (FEV_{25-75}), peak expiratory flow (PEF) and forced vital capacity (FVC) were selected.

Statistical analysis

Data were analysed using SPSS version 20 (IBM Corp., USA). Data were tested for normality using the Shapiro-Wilk's test and parametric tests were employed. An independent sample *t*-test was used to determine mean differences of continuous variables between males and females. Data were presented as mean (standard deviation (SD). Pearson's correlation was used to assess the relationship between PM and lung function. Differences with a $p \leq 0.05$ were considered significant.

Results

Distribution of PM in classrooms

The average PM_5 level in the classrooms ranged between 75.39 and 299.00 µg/m^{3,} with a mean (SD) level of 109.96 (75.39) µg/m^3. PM_{10} had a mean (SD) level of 84.84 (63.28) µg/m^3, which ranged between 63.28 and 245.00 µg/m^3. $PM_{2.5}$ ranged from 11.43 to 99.37 µg/m^{3,} with a mean (SD) value of 39.45 (26.38) µg/m^3. The PM_5 level was higher than PM_{10} and $PM_{2.5}$ levels (Table 1).

Lung function indices in children

Lung function indices (FVC, percentage forced vital capacity (PFVC), FEV_1, PEF, and FEV_1/FVC) were not different ($p>0.05$) between males and females. However, $PFEV_1$ was higher ($p<0.05$) in males, while percentage peak expiratory flow (PPEF) and FEV_1/FVC ratio ($p<0.05$) values were higher in females (Table 2).

Relationship between PM and lung function indices

The relationship between PM and lung function indices shows that all the PM ($PM_{2.5}$, PM_5 and PM_{10}) correlated negatively ($p<0.05$) with FVC, FEV_1, PEF and FEV_{25-75} but correlated positively ($p<0.001$) with the FEV_1/FVC ratio, which implies that PM is associated with lung function indices (Table 3).

Discussion

The present cross-sectional study measured PM in classrooms and assessed the relationship of PM with lung function in schoolchildren while they were seated in class. The main finding of this study revealed that PMs was associated negatively with lung function in children, i.e. an increase in PM count was associated with a decrease in lung function. More so, the $PM_{2.5}$ level was above the World Health Organization (WHO) Air Quality Guidelines (AQG) level of 25 µg/m^3 but below the SA National Ambient Air Quality Standards (NAAQS) limit of 40 µg/m^3. The PM_{10} level was above the WHO AQG limit. This finding concurs with previous studies in SA where PM_{10} and $PM_{2.5}$ levels in winter were above the WHO and NAAQS limit.[6,7] This finding suggests that PM is high in winter when rainfall is very low, thus creating an environment conducive to windblown dust.

It is important to note that the present study was carried out in winter when windows were closed throughout school hours. Consequently, PM created by classroom activities remained floating in the classroom and was not driven away by fresh air. The high PM counts observed in our study suggest chronic exposure of these schoolchildren to PM, which may place them at higher risk of impaired lung function, pulmonary diseases and illness associated with lung function. Assessing the relationship between PM and lung function indices showed that $PM_{2.5}$, PM_5 and PM_{10} were negatively associated with lung function indices, i.e. FVC, FEV_1, PEF and FEV_{25-75}, suggesting a decrease in lung function. Therefore, increased PM can impair mechanical properties of the lungs and chest wall. Similar findings have been reported in children in other locations and ethnic populations across the world. A US study showed that children exposed to higher $PM_{2.5}$ concentrations

Table 1. Particulate matter distribution

Particle	Mean (SD)	Minimum	Maximum	Range
$PM_{2.5}$	39.45 (26.38)	11.43	99.37	87.93
PM_5	109.96 (75.39)	30.00	299.00	269.00
PM	84.84 (63.28)	21.00	245.00	224.00

SD = standard deviation; $PM_{2.5-10}$ = airborne particulate matter (tiny particles or droplets) that are 2.5, 5 or 10 µm in diameter.

Table 2. Lung function indices in children

Parameter	Females, mean (SD)	Males, mean (SD)	*p*-value
FVC (L)	2.01 (0.43)	2.06 (0.52)	0.207
PFVC (%)	76.95 (11.97)	75.02 (12.22)	0.066
FEV_1 (L)	1.79 (0.35)	1.81 (0.43)	0.616
$PFEV_1$	74.35 (11.43)	76.52 (11.69)	0.030
PEF	4.25 (1.31)	4.09 (1.26)	0.152
PPEF	93.30 (23.45)	84.22 (21.95)	<0.001
FEV_1/FVC	0.90 (0.08)	0.89 (0.08)	0.130
FEV_{25-75}	2.48 (0.71)	2.34 (0.69)	0.016

SD = standard deviation; FVC = forced vital capacity; PFVC = percentage forced vital capacity; FEV_1 = forced expiratory volume in 1 second; $PFEV_1$ = percentage forced expiratory volume in 1 second; PEF = peak expiratory flow; PPEF = percentage peak expiratory flow; FEV_{25-75} = forced expiratory volume between 25% and 75% of vital capacity.

Table 3. Correlation between particulate matter and lung function parameters

	$PM_{2.5}$		PM_5		PM_{10}	
Parameter	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
FVC	−0.224***	<0.001	−0.296***	<0.001	−0.284***	<0.001
FEV_1	−0.173***	<0.001	−0.246***	<0.001	−0.249***	<0.001
PEF	−0.221***	<0.001	−0.160***	<0.001	−0.162***	<0.001
FEV_1/FVC	0.134***	0.001	0.161***	<0.001	0.138***	0.001
FEV_{25-75}	−0.125**	0.002	−0.071*	0.049	−0.071*	0.049

PM2.5-10 = airborne particulate matter (tiny particles or droplets) that are 2.5, 5 or 10 µm in diameter; *r* = correlation coefficient; FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; PEF = peak expiratory flow; FEV_{25-75} = forced expiratory volume between 25% and 75% of vital capacity.
*$p<0.05$.
**$p<0.01$.
***$p<0.001$.

had an ~80 mL lower FEV_1 than children exposed to the lowest level of PM.[8] Also, a longitudinal study involving 179 schoolchildren in Britain showed that higher PM levels were associated with lower PEF values.[9] More so, some studies have reported that rural areas may be more prone to severe cases of respiratory symptoms and diseases.[10] Findings of the present study suggest that PM exposure could have short- and long-term effects on lung function in SA children although such studies are lacking in African populations.

Study strengths and limitations

The strength of this study is that it utilised a large sample size with a strong statistical power. However, the study was limited to spirometry analysis and did not assess other lung function parameters such as functional residual capacity (FRC), total lung capacity (TLC), and expiratory residual volume (ERV) which are important aspects of lung mechanics. Also, as this was a cross-sectional study, we could not monitor the impact of PM on lung function over time. Therefore, it will be of interest to further assess the long-term impact of PM on lung function and associated consequences in children in this population using longitudinal models.

Conclusion

Findings from the present study revealed that PM levels in classrooms were above the WHO daily limits and negatively associated with lung function in children in an SA population. This calls for monitoring of PM in classrooms for the prevention of pulmonary diseases. Further studies using a longitudinal model will be of interest to assess the long-term impact of PM on lung function and pulmonary diseases.

Declaration. None.

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Author contributions. BNN-C designed the study. CA performed the field work and data collection. GAE, CA and BNN-C analysed and interpreted the data. GAE drafted the manuscript. BNN-C and GAE reviewed and revised the manuscript. All authors proofread and approved the final manuscript.

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Conflicts of interest. None.

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