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The Diesel School Bus Particulate Filter Retrofit Program in Cleveland: Evaluating Bus Self-Pollution and Asthma through a Partnership to Reduce Health Disparities.

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Title: The Diesel School Bus Particulate Filter Retrofit Program in Cleveland: Evaluating Bus Self-Pollution and Asthma through a Partnership to Reduce Health Disparities.

Running Head: Partnership to Reduce Health Disparities Through a School Bus Retrofit Program.

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ABSTRACT

Background: In efforts to improve outdoor air quality, a Cleveland school district retrofitted school buses with diesel particulate filters (DPFs). With this opportunity, a community-based research project on bus pollution and asthma was performed. **Methods:** PM pollution levels were measured in buses before and after DPF installation, and school nurse visits for asthma medications were compiled. **Results:** Before DPF installation, PM 2.5 and ultrafine levels were 5 to 36-fold higher than ambient levels, and post DPF, the pollutant levels were attenuated by 50-80%. Evaluation of school data demonstrated no reduction of asthma inhaler administration in the school offices during the time course of the retrofit program. **Discussion:** DPF installation decreased school bus emissions both inside and outside the buses, and though impact upon the schoolchildren cannot be accurately assessed, this study underscores the importance of creative partnerships and remediation of asthma triggers for a group at high risk for asthma.

Keywords:

Health disparities; asthma; children; school bus; self-pollution; particulate matter

INTRODUCTION

Similar to many other urban metropolitan areas, Cleveland faces challenges with health disparities among its residents [1-3]. A combination of factors contribute towards a disproportionate burden of asthma, including a unique mix of allergies, outdoor air quality, and a challenging healthcare climate leaving many uninsured [4, 5]. In 2004, the Greater Cleveland Asthma Coalition, supported by the American Lung Association, compiled data on asthma reported in in the area [2]. Sources included school health programs at the County Board of Health, family health surveys, and screening questionnaires in schools administered by the local children's hospital. In certain areas of Cleveland, 22% of children reported a diagnosis of asthma, and 16-32% of children reported symptoms of asthma without an established diagnosis. As compared to the general United States population in which the prevalence of asthma is 8%, data from a 2005-2009 Cuyahoga County Behavioral Risk Factor Surveillance Survey (BRFSS) noted that 10.5% to 14.7% of people living in greater Cleveland have asthma [6]. Addressing these disparities requires a comprehensive approach [7]. Growing partnerships in the community with healthcare providers, members of the American Lung Association (ALA), and regional air quality advocates have resulted in various initiatives including capitalization of a school bus diesel particulate filter (DPF) retrofit program.

Population studies have shown an association of poor air quality from both ozone and particulate matter (PM) pollution with adverse health effects, particularly among those with chronic respiratory diseases such as asthma [8-12]. Outdoor air quality in the Cleveland area has been poor due to both vehicular and industrial sources, with higher pollutant levels than the standards set forth by the United States Environmental Protection Agency (USEPA). Ozone levels only recently improved to within standards, however levels of particulate matter (PM) still remain high [5]. PM pollution, also known as soot, is created by multiple sources including from combustion of fossil fuels. Studies have shown that DPFs reduce diesel engine emissions by as much as 90% [13-16]. When installed on school buses, DPFs also have the potential benefit of reducing in-cabin PM levels (“self-pollution”) which can rise when entrained pollutants enter the cabin [17, 18].

The Cleveland Municipal School District (CMSD), located in Northeast Ohio, is among the largest school districts in the nation, with 50-60,000 students enrolled yearly [19]. In a collaborative effort to improve regional air quality, the school district bus maintenance department and the Clean Air Century Campaign partnered to retrofit the fleet of diesel school buses with diesel particulate filters (DPFs). Support was obtained from federal and private agencies including the United States Environmental Protection Agency (USEPA), the American Lung Association, and private charitable foundations. From 2002 to 2008 the maintenance department retrofitted nearly the entire fleet of 315 buses in the district.

To demonstrate reduction in bus self-pollution locally and explore the potential health benefits from the retrofit program, an observational community-based research project was initiated with individuals from the CMSD bus maintenance department, CMSD school nursing, the ALA, area nursing and graduate students, and local healthcare providers.

METHODS

This study was a local observational proof of concept study of diesel school bus self-pollution before and after DPF installation. Information was also collected on school enrollment to determine the number of children who might be affected by this program. Further, a metric of asthma morbidity, school nurse visits to use symptom-relief asthma inhalers or nebulizers (‘bronchodilators’), was compiled to assess any changes during this time. Since there was no identifiable demographic or health information collected, the Institutional Review Board deemed the study exempt from Review. Similarly, the observational study evaluating levels of emitted pollution from buses did not require special institutional approval.

Bus Tailpipe Emission and Self-pollution Evaluation before and after DPF installation.

Two buses were studied in similar fashion for this portion of the study. These buses were scheduled for DPF installation and were available for pre and post DPF pollutant measurements. PM levels outside and inside the bus were measured before and after DPFs were installed. Particulate matter concentrations of 2.5 micron diameter or less (PM2.5 mg/m^3) were measured using the SidePak AM510® (TSI Incorporated, Shoreview MN). Trachebronchial and alveolar deposition fractions of ultrafine particles (diameter <0.1 μm) were measured with the Aerotrack® Nanoparticle aerosol monitor. This instrument has been used for industrial hygiene assessments and can detect surface area of particle matter fractions ($\mu m^2/cc$) that tend to deposit in either the tracheobronchial or alveolar portion of the lung.

Baseline ambient measures of PM levels were obtained within and outside the cabin while the engine was off. After the bus diesel engine was started, the vehicle was left idling for two minutes and measurements were then taken at the tailpipe. Additional measurements of PM levels during a simulated bus route were performed: inside the bus cabin at the rear and at the front of the cabin, with windows closed and open, with the engine idling and while the bus was in motion, and with simulated bus stops. A similar measurement protocol was repeated on the same buses after DPF installation one week later. Data from measurements were recorded every

30 seconds, saved in the instrument's memory and then downloaded to an external database (TrakPro™, TSI Incorporated).

Mean and median values were calculated for each stage of measurement. Absolute values were not compared due to the variability in ambient air pollution (PM) levels and meteorologic conditions on the two days of evaluation. Instead, data was examined as multiple of change from baseline, i.e. by dividing the measured PM levels by the baseline ambient measurement levels. Given the observational nature of the study in a sample of two representative buses, no tests of statistical significance were performed.

Review of School Clinic Visits for Asthma Symptom Medication Use:

All active school buses (315) in the CMSD fleet were retrofitted with DPFs over the 6 year time period from 2002-2008. Based on public records, approximately 40% of the children attending CMSD ride school buses to and from school. In order to observe any potential pattern or changes in frequency of bronchodilator use, a retrospective review of school clinic charts was performed in 23-26 schools from 2002-2007 and 16 schools in 2007-2008 (Table 1). School characteristics such as attendance rate and mobility rate were obtained through the Ohio Department of Education website [19, 20]. These schools were chosen by convenience sampling from involvement with the local ALA initiative to promote better air quality (EPA Indoor Air Quality Tools for Schools Program) [21]. In each school, paper records on school nurse/office visits had been kept by the school nursing or front office staff. Though names or unique identifiers were not used and reasons for visits were not consistently documented, bronchodilator administration by either inhaler or nebulizer was recorded. Monthly number of student clinic visits was also obtained for each school and transferred to electronic databases by study staff.

Statistical analysis was performed with SAS (SAS Institute Inc., Cary, NC) and STATA (StataCorp LP, College Station, TX). Linear regression analysis was performed with proportion of bronchodilator visits as the outcome and proportion of bus retrofits, year, and surrogates for student body stability (e.g. attendance and mobility rate) as variables.

RESULTS

During the school year from 2002-2003, 84 diesel school buses were on the active fleet for the district. At that time, none of the buses had been retrofitted with DPFs. By the 2007-2008 school year, 62 of the 69 (90%) buses in service were retrofitted with the DPFs. These buses served the entire school district including the schools from which school nurse visit data was collected.

Bus Tailpipe Emission and Self-Pollution Evaluation.

Numeric values for both buses while off, idling, and driving are outlined in Tables I and II. PM2.5 concentrations were two-fold higher inside the back of Bus A while idling as compared to baseline ambient levels (Table I). While the bus was in motion with windows closed, PM levels inside the bus at the back and front were 17 to 25-fold higher than baseline outdoor levels. Ultrafine particles predisposed to alveolar deposition increased 22-36 fold and tracheobronchial deposition fraction increased 18-30 fold. Post DPF, Bus A PM increases were attenuated: levels during idling did not increase and during driving the increase was 12-17% of prior levels. Though measured PM levels inside Bus B did not demonstrate the magnitude of change seen in Bus A, a 5-fold increase of PM2.5 inside the back of the bus during idling and 10-fold in the front while bus was in motion was noted (Table II). Ultrafine alveolar and tracheobronchial deposition fractions also doubled. Post DPF, PM 2.5 concentration levels were not available, however the ultrafine particle levels were halved as compared to pre-DPF values. Notably, regardless of whether DPFs were in place, proper ventilation of bus cabins with all windows open also demonstrated a significant reduction or attenuation in-cabin levels of PM.

Review of School Clinic Visits for Inhaler Use:

From 2003-2006, over 20 of 84 ‘Pre-K through 8’ CMSD schools were selected for data collection, however due to school closings, restructuring, and/or office record availability, data on only 16 schools were available for 2007-2008. Total attendance in these schools ranged from 11,000 to 14,000 with an attendance rate greater than 90%. The mobility rate approached and surpassed 25%, indicating a group of children with low residential stability (Table III). In the entire school system for these years, self-reported race distribution was 65-71% African American, 10-15% Hispanic, 16-18% White, and 1-2% multiracial [19]. To adjust for variability in enrollment, bronchodilator administrations per 100 school clinic visits were used as a marker for asthma morbidity. During the initial school year of the study in 2002-2003, for every 100 school clinic visits, there were 5.8 visits for any type of bronchodilator (nebulizer or inhaler) administration. A slight increase in these visits was noted through the 2004-2005 school year with 6.8 visits for bronchodilator administration for every 100 school clinic visits followed by a subsequent decline during the 2007-2008 school year to a low of 2.82 (Table III). Using statistical models including linear regression, controlling for confounders such as attendance and mobility rate, no statistically significant change in bronchodilator administration was noted during the period studied.

DISCUSSION

Cleveland has recently been cited as one of the 30 worst places in the United States to live with asthma. This designation was compiled from metrics of air quality, allergens, number of patients without insurance, and proportion of Emergency Department visits for asthma [4, 22]. It is also well known that asthma is a chronic condition in which significant health disparities exist, and a high proportion of children suffer from asthma symptoms in our area [2, 23]. Addressing these disparities require a multifactorial approach, and communities can capitalize on initiatives that have multiple benefits. In addition to measuring PM 2.5 concentrations of bus self-pollution before and after DPF installation, this is the first study to our knowledge characterizing levels of ultrafine PM most likely to deposit in the trachebronchial and alveolar areas of the lung. Efforts were also made to measure metrics of asthma morbidity, measured by school clinic visits for bronchodilators, during this period of interest to provide a glimpse into asthma status in a subset of schools.

Prior studies have demonstrated factors that increase school-bus self-pollution, including closed windows, idling, and traffic in the near vicinity [15, 16]. These studies demonstrated that children commuting in congested urban areas were exposed to significantly worse air quality through bus self-pollution than would occur from ambient outdoor air alone [24, 25]. The buses in this report did demonstrate different baseline and changes in bus self-pollution, possibly due to variable weather and wind conditions as well as intrinsic mechanical properties of the buses. Despite these differences, our current evaluation distinctly demonstrates that rear internal cabins of diesel school buses have high amounts of self-pollution that improved after DPF installation. Proper ventilation with open windows also helped to reduce in-cabin pollution levels.

Models in simulated healthy and diseased lungs have demonstrated that fine PM (PM2.5 µM diameter or less) deposits in the 20th generation of the branching points, representing the lower bronchial fractions [26]. Lungs are normally resilient and able to protect the body from inhaled toxins and particles, however characteristics of these particles may affect airways, worsening allergies and asthma [27, 28]. Large epidemiologic studies have demonstrated that children exposed to higher PM levels have worse asthma symptoms and attenuation of lung growth [29, 30]. In this study, instruments were able to separate the pollution fractions that are most likely to deposit in the tracheobronchial (earlier branching points) as compared to alveolar (terminal gas exchange units) portions of the lungs and showed high bus levels of both. Such evaluation of surface chemistry and fraction of deposition in various area of the respiratory system appear to play an important role in toxicity and warrants further study [26, 30, 31].

There are potential implications for school health related to this study. A high mobility rate as demonstrated in our schools speaks to the fluid nature and challenges to educational, health, financial, and psychosocial stability available to these children [20]. In a susceptible population of school children with high prevalence of asthma, improving air quality in buses may contribute towards lowering asthma morbidity [2]. As the nature of data availability and collection was not structured to address this question, there were limitations to this study approach: Multiple individual home, medication, and infection-related reasons could influence potential effects on asthma metrics from reduction of diesel particle exposures. In addition, only 40% of children ride buses to school, the characteristics of the student body may have changed, and child or complaint-specific data was not available (for example, 10 visits per month may have been from 1 child or 2 visits by 5 children). Finally, during this time legislation had been enacted in Ohio allowing school children to possess and use asthma inhalers while in school

(Ohio Rev Code Ann 3313.716 (2004)). Due to this increased immediate access to rescue inhalers, many children would not need to visit the school nurse to receive symptomatic care.

While DPF installation decreased school bus emissions both inside and outside the buses, and the impact upon the health of schoolchildren was not directly measurable, this program underscored the importance of community-based research that allows exploration and remediation of asthma triggers. DPF installations, coupled with improved ventilation strategies, is likely to reduce asthma morbidity in this susceptible group of children [32-37]. Using this data has been powerful to gain interest from various groups: school administration, public health officials, as well as bus drivers. The proactive approach towards air quality was consistently demonstrated by the school transportation administration; As the retrofit program was ongoing over several years, programs to reduce school bus idling were implemented as well, with electronic engine block heaters and policies to reduce idling near school yards or waiting at bus stops. Further, in October 2009, the city of Cleveland enacted a private vehicle idle reduction ordinance.

CONCLUSIONS

The experience of this DPF retrofit program, with its collaborative approach, is an example of how an initiative that is seemingly single-purposed can have collateral good effects. The benefits include increased awareness of air quality issues, improved bus self-pollution, and strengthened community partnerships from stakeholders in healthcare, public health, and educational organizations. Proving a return on investment with specific metrics such as reducing asthma morbidity is difficult when only one of a possibility of multi-modal interventions is used, however adaptive, transformational, and community-based approaches to health care are a necessary component of community health.

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Figure and Table Legends

Table I. Bus A external and in-cabin 2.5 μm and ultrafine particulate matter levels pre and post-diesel particulate filter (DPF) installation with variable engine status, bus motion, and window ventilation.

Table II. Bus B external and in-cabin 2.5 μm and ultrafine particulate matter levels pre and post-diesel particulate filter (DPF) installation with variable engine status, bus motion, and window ventilation.

Table III. School characteristics and nurse visits for bronchodilator use for time period where no buses (2002) and subsequently nearly all buses (2008) had Diesel Particulate Filters installed.

Table I. Bus A external and in-cabin 2.5 um and ultrafine particulate matter levels pre and post-diesel particulate filter (DPF) installation with variable engine status, bus motion, and window ventilation.

**Change denotes proportion of change from baseline (ambient PM levels at tailpipe with engine off).*

BUS A	**OUTSIDE**				**INSIDE**											
Pre-DPF (9-15-08)																
Motion	**Stop**	*Change*	**Stop**	*Change*	**Stop**	*Change*	**Stop**	*Change*	**Stop**	*Change*	**Driving**	*Change*	**Driving**	*Change*	**Driving**	*Change*
Location	**tailpipe**		**tailpipe**		**back/inside**		**Back/inside**		**Front/inside**		**Back**		**Front**		**Front/Window Open**	
Engine status (Off/On/Idling)	**OFF**		**ON**		**OFF**		**ON (IDLING)**		**ON (IDLING)**		**ON**		**ON**		**ON**	
	(Ambient)															
	reference															
PM 2.5 concentration (mg/m3)																
60 s mean	0.003	***1***	0.027	***9.0***	0.004	***1.3***	0.007	***2.3***	0.005	***1.7***	0.053	***17.7***	0.076	***25.3***	0.003	***1.0***
60 s median	0		0.004		0.002		0.001		0.001		0.04		0.073		0.002	
Range for the 60 s	(0-0.101)		(0.00-0.19)		(0-0.057)		(0-0.24)		(0-0.047)		(0.022-0.268)		(0.049-0.134)		(0.00-0.034)	
Ultrafine (<0.1 uM) PM *(µm2/cm3)*																
Alveolar deposition	5.42	***1***	1949.9	***359.8***	6.39	***1.2***	6.80	***1.3***	6.28	***1.2***	119.09	***22.0***	197.09	***36.4***	17.03	***3.1***
	(3.69-7.26)		(46.43-10328.1)		(6.02-6.73)		(5.97-7.36)		(5.48-7.32)		(91.88-135.30)		(178.41-212.21)		(9.3-37.59)	
Tracheobronchial deposition	1.2	***1***	740.61	***617.2***	1.56	***1.3***	1.91	***1.6***	1.94	***1.6***	22.69	***18.9***	36.39	***30.3***	3.58	***3.0***
	(1.02-1.43)		(1.63-2256.16)		(1.47-1.66)		(1.73-2.24)		(1.5-2.43)		(20.81-25.68)		(35.32-38.62)		(1.76-8.77)	
Post-DPF (9-22-08)																
PM 2.5 concentration (mg/m3)																
60 s mean	0.06	***1***	0.037	***0.6***	0.066	***1.1***	0.048	***0.8***	0.044	***0.7***	0.218	***3.6***	0.191	***3.2***	0.037	***0.6***
60 s median	0.06		0.035		0.065		0.044		0.038		0.190		0.173		0.032	
Range for the 60 s	(0.037-0.096)		(0.024-0.087)		(0.047-0.108)		(0.031-0.092)		(0.022-0.272)		(0.127-0.660)		(0.075-0.509)		(0.019-0.136)	
Ultrafine (<0.1 uM) PM *(µm2/cm3)*																
Alveolar deposition	90.64	***1***	26.69	***0.3***	70.2	***0.8***	30.56	***0.3***	29.83	***0.3***	74.13	***0.8***	88.64	***1.0***	41.91	***0.5***
	(86.8-93.97)		(25.76-28.06)		(68.25-71.39)		(30.48-30.93)		(29.08-30.29)		(64.3-89.95)		(81.03-98.65)		(41.36-42.6)	
Tracheobronchial deposition	20.31	***1***	7.14	***0.4***	16.5	***0.8***	7.76	***0.4***	7.23	***0.4***	19.3	***1.0***	20.58	***1.0***	11.29	***0.6***
	(19.38-20.88)		(6.34-8.9)		(14.08-17.3)		(7.66-7.90)		(7.07-7.55)		(16.69-23.13)		(17.00-22.59)		(10.95-11.55)	

Table II. Bus B

Table II. Bus B external and in-cabin 2.5 um and ultrafine particulate matter levels pre and post-diesel particulate filter (DPF) installation with variable engine status, bus motion, and window ventilation.

**Change denotes proportion of change from baseline (ambient PM levels at tailpipe with engine off).*

BUS B			**OUTSIDE**					**INSIDE**				
Pre-DPF (9-15-08)												
Motion	**Stop**	*Change*	**Stop**	*Change*	**Stop**	*Change*	**Stop**	*Change*	**Driving**	*Change*	**Driving**	*Change*
Location	**tailpipe**		**tailpipe**		**back/inside**		**back/inside**		**Front**		**Front/Window Open**	
Engine	**OFF**		**ON**		**OFF**		**ON**		**ON**		**ON**	
	(Ambient)											
	reference											
PM 2.5 concentration (mg/m3)												
60 s mean	0.003	***1***	0.008	***2.7***	0.003	***1.0***	0.016	***5.3***	0.029	***9.7***	0.0119	***4.0***
60 s median	0.003		0.004		0.002		0.011		0.016		0.007	
Range for the 60 s	(0.001-0.028)		(0.001-0.038)		(0.001-0.025)		(0.004-0.063)		(0.003-0.318)		(0.003-0.095)	
Ultrafine (<0.1 uM) PM *(µm2/cm3)*												
Alveolar deposition	4.38	***1***	139.14	***31.8***	5.23	***1.2***	8.94	***2.0***	8.65	***2.0***	7.21	***1.6***
	(3.82-5.15)		(5.95-990.2)		(4.90-5.60)		(8.50-9.50)		(8.32-9.01)		(5.89-12.96)	
Tracheobronchial deposition	1.15	***1***	4.13	***3.6***	1.38	***1.2***	2.24	***1.9***	2.33	***2.0***	2.84	***2.5***
	(1.04-1.23)		(2.04-10.12)		(1.31-1.45)		(2.07-2.35)		(2.29-2.40)		(2.17-3.4)	
Post-DPF (9-22-08)												
PM 2.5 concentration (mg/m3)												
60 s mean	0.029	***1***	0.039	***1.3***	0.029	***1.0***	-		-		-	
60 s median	0.026		0.03		0.026							
Range for the 60 s	(0.017-0.056)		(0.018-0.158)		(0.016-0.098)							
Ultrafine (<0.1 uM) PM *(µm2/cm3)*												
Alveolar deposition	64.33	***1***	81.18	***1.2***	65.68	***1.0***	65.79	***1.0***	72.92	***1.1***	87.1	***1.4***
	(63.61-65.49)		(77.64-98.04)		(64.79-66.26)		(64.05-67.08)		(71.80-74.31)		(86.05-88.56)	
Tracheobronchial deposition	18.63	***1***	22.14	***1.2***	17.84	***1.0***	16.70	***0.9***	19.11	***1.0***	22.42	***1.2***
	(18.50-18.76)		(21.9-22.3)		(17.69-18.04)		(16.34-17.14)		(18.57-19.49)		(22.18-22.64)	

Table III. School characteristics and nurse visits for bronchodilator use for time period where no buses (2002) and subsequently nearly all buses (2008) had Diesel Particulate Filters installed.

Year	**2002-3**	**2003-4**	**2004-5**	**2005-6**	**2006-7**	**2007-8**
Schools sampled (n)	23	26	26	25	25	16
Total attendance	14246	13719	12428	12459	11583	10969
Mobility rate (%)*	NA	15.4	18.0	23.4	32.3	26.3
Attendance (%)	94.8	95.0	95.0	92.0	93.5	92.7
Number of school clinic visits	35792	38192	37099	46280	35443	11897
visits for BD (total)	2057	2483	2534	2992	1956	335
MDI	1821	2418	2242	2624	1751	316
Nebs	236	65	292	368	205	19
BD/ 100 Visits	5.7	6.5	6.8	6.5	5.5	2.8
BD/Enrollment	0.144	0.181	0.204	0.240	0.169	0.031

[a]Mobility rate= data on student mobility between schools within a district or out of the district;
[b] BD=Bronchodilator
NA-data unavailable.