NEIGHBORS FOR CLEAN AIR

June 29, 2017

To: JOINT COMMITTEE ON WAYS AND MEANS SUBCOMMITTEE ON NATURAL RESOURCES

My name is Mary Peveto, I am president and founder of Neighbors for Clean Air (NCA). NCA is a non-profit organization established in 2010 that works to protect and improve the health of Oregonians through the reduction of toxic air emissions.

Thank you for the opportunity to testify in support of SB 1008.

While SB 1008 in its current form falls well short of our members' goal to realize swift and significant reductions of diesel particulate emissions in Oregon, NCA does support the work to address the unique problem of Oregon's school bus fleet.

Children are uniquely susceptible to the impacts of air pollution. Not only do their smaller lungs breathe more quickly and deeper in comparison to their relative size to adults, but the fact that their lungs and brains are still developing, make the long term health impacts more significant.

Emerging science has proven that exposure to Diesel PM emissions, long considered to be an asthma trigger, was upgraded to a known human carcinogen by the World Health Organization in 2014, and is increasingly linked to other non-respiratory risks like neurodevelopmental problems such as ADHD and even Alzeiheimers.

To that end, with my support to pass SB 1008, and the funding for school bus clean up through the VW settlement, I would like to underscore that time is of the essence. With my written testimony, I submitted a study done in the wake of successful school bus clean up program in Washington State a decade ago (the same time Oregon passed its current school bus law). Studies of children's lung health showed that clean school bus technology was linked not only to improved lung function, but also subsequently to reductions in school absenteeism among students. This is a demonstration of remarkable efficacy for a public health initiative. So I would hope to urge school districts to act well before the allowed 2025 deadline to clean up any buses, particulary the estimated 400 which will not be ready for replacement by the 2025 deadline in any event.

Sincerely,

Mary S. Peveto

Mary Peveto, President

incorporated into the clinical prediction model. Using additional biomarkers may further improve the detection of subclinical RA-ILD.

Nevertheless, this study from Doyle and colleagues demonstrates that a clinical prediction model incorporating clinical factors, antibodies, and biomarkers can detect patients with RA-ILD with impressive accuracy, including those with subclinical disease (7). Whether these variables are associated with disease progression and/or longitudinal outcomes in patients with RA-ILD is an important question to be addressed in future studies.

The utility and limitations of this work are only half the story. The objective to this approach reveals broader implications that align with this investigative group's prior work. The objective helps identify pathways and mechanisms involved in early triggers to disease development. Commonly in medicine, the earlier we initiate interventions, the greater the chance to alter disease course. Because one-third of patients with RA may have subclinical disease, and more than 50% of patients with RA-ILD have progressive fibrosis, identifying these patients provides an opportunity for early intervention (6). The approach of blending molecular markers and clinical factors is not the wave of the future but the here and now. Integrating molecular elements of ILD and linking them to the clinical elements of RA helps in identifying important phenotypes for study and treatment. Now that there are two approved therapies for IPF in nintedanib and pirfenidone, the next natural step will be application in other ILDs, especially those such as RA-ILD that may share important clinical or histological similarities to IPF (12, 13). But the first step is in identifying such cases. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

Rekha Vij, M.D.
Section of Pulmonary and Critical Care Medicine
University of Chicago
Chicago, Illinois

Christopher P. Denton, M.B. B.S.
University College London Medical School
Royal Free Hospital
London, United Kingdom

Imre Noth, M.D.
Section of Pulmonary and Critical Care Medicine
University of Chicago
Chicago, Illinois

References

1. Sacks JJ, Luo YH, Helmick CG. Prevalence of specific types of arthritis and other rheumatic conditions in the ambulatory health care system in the United States, 2001-2005. *Arthritis Care Res (Hoboken)* 2010;62:460–464.
2. Olson AL, Swigris JJ, Sprunger DB, Fischer A, Fernandez-Perez ER, Solomon J, Murphy J, Cohen M, Raghu G, Brown KK. Rheumatoid arthritis-interstitial lung disease-associated mortality. *Am J Respir Crit Care Med* 2011;183:372–378.
3. Minaur NJ, Jacoby RK, Cosh JA, Taylor G, Rasker JJ. Outcome after 40 years with rheumatoid arthritis: a prospective study of function, disease activity, and mortality. *J Rheumatol Suppl* 2004;69:3–8.
4. Koduri G, Norton S, Young A, Cox N, Davies P, Devlin J, Dixey J, Gough A, Prouse P, Winfield J, *et al*.; ERAS (Early Rheumatoid Arthritis Study). Interstitial lung disease has a poor prognosis in rheumatoid arthritis: results from an inception cohort. *Rheumatology (Oxford)* 2010;49:1483–1489.
5. Bongartz T, Nannini C, Medina-Velasquez YF, Achenbach SJ, Crowson CS, Ryu JH, Vassallo R, Gabriel SE, Matteson EL. Incidence and mortality of interstitial lung disease in rheumatoid arthritis: a population-based study. *Arthritis Rheum* 2010;62:1583–1591.
6. Gochuico BR, Avila NA, Chow CK, Novero LJ, Wu HP, Ren P, MacDonald SD, Travis WD, Stylianou MP, Rosas IO. Progressive preclinical interstitial lung disease in rheumatoid arthritis. *Arch Intern Med* 2008;168:159–166.
7. Doyle TJ, Patel AS, Hatabu H, Nishino M, Wu G, Osorio JC, Golzarri MF, Traslosheros A, Chu SG, Frits ML, *et al*. Detection of rheumatoid arthritis–interstitial lung disease is enhanced by serum biomarkers. *Am J Respir Crit Care Med* 2015;191:1403–1412.
8. Chen J, Doyle TJ, Liu Y, Aggarwal R, Wang X, Shi Y, Ge SX, Huang H, Lin Q, Liu W, *et al*. Biomarkers of rheumatoid arthritis-associated interstitial lung disease. *Arthritis Rheum (Munch)* 2015;67:28–38.
9. Vij R, Noth I. Peripheral blood biomarkers in idiopathic pulmonary fibrosis. *Transl Res* 2012;159:218–227.
10. Kelly CA, Saravanan V, Nisar M, Arthanari S, Woodhead FA, Price-Forbes AN, Dawson J, Sathi N, Ahmad Y, Koduri G, *et al*.; British Rheumatoid Interstitial Lung (BRILL) Network. Rheumatoid arthritis-related interstitial lung disease: associations, prognostic factors and physiological and radiological characteristics: a large multicentre UK study. *Rheumatology (Oxford)* 2014;53:1676–1682.
11. Ascherman DP. Interstitial lung disease in rheumatoid arthritis. *Curr Rheumatol Rep* 2010;12:363–369.
12. Richeldi L, du Bois RM, Raghu G, Azuma A, Brown KK, Costabel U, Cottin V, Flaherty KR, Hansell DM, Inoue Y, *et al*.; INPULSIS Trial Investigators. Efficacy and safety of nintedanib in idiopathic pulmonary fibrosis. *N Engl J Med* 2014;370:2071–2082.
13. King TE Jr, Bradford WZ, Castro-Bernardini S, Fagan EA, Glaspole I, Glassberg MK, Gorina E, Hopkins PM, Kardatzke D, Lancaster L, *et al*.; ASCEND Study Group. A phase 3 trial of pirfenidone in patients with idiopathic pulmonary fibrosis. *N Engl J Med* 2014;370:2083–2092.

The Engine on the Bus Goes Vroom, Vroom, Vroom!
And the Fumes on the Bus Go . . . ?

For more than a decade, elevated air pollution levels inside school buses have been recognized as an insidious hazard that may affect the health of ~25 million U.S. children who commute to school in diesel-powered school buses each day. Concentrations of traffic-related air pollutants (TRAP) reported inside school buses are up to severalfold higher than ambient background levels (1). What are the health effects of these short-term, but relatively intense, exposures to children? This question is amplified by concerns that children are likely to be especially susceptible to the health effects of air pollution (2).

Emissions from diesel engines are a major source of the complex mixtures of fine and ultrafine particulate and gas-phase compounds that make up TRAP. In numerous studies, TRAP has been associated with a growing list of acute and chronic adverse health effects (3). Of particular importance to children is the established association between short-term exposure to TRAP and exacerbation of asthma (4), as well as emerging evidence linking long-term exposures to reduced lung growth (5), incident asthma (6), obesity (7), and neurocognitive deficits (8).

These exposures and potential health effects are largely preventable: available control technologies can substantially reduce emissions from heavy-duty diesel bus engines, reducing in-cabin concentrations of TRAP. However, newer, cleaner engines and emission control retrofits are not inexpensive and may present a large fiscal burden to local school systems. Do efforts to reduce emissions and exposures make a difference in health outcomes that matter to children and their families, schools, and society at large? In this issue of the *Journal*, Adar and colleagues (pp. 1413–1421) set out to answer that question (9). Their study was conceived and led by the principal investigator, L. J. Sally Liu, before her untimely death several years ago.

As previously conceptualized by Adar and others, total exposure of children to TRAP onboard school buses is the sum of pollutant concentrations arising from a dynamic interplay of three main sources: ambient background pollution, pollution from other surrounding vehicles, and self-pollution, or entrainment of emissions from the tailpipe or engine into the bus cabin (10). Control technologies can reduce self-pollution, as well as contributions to exposures that occur outside of the bus (11).

U.S. Environmental Protection Agency regulations have mandated reductions of at least 90% in particulate matter emissions from heavy-duty diesel engines, starting in 2007. However, the useful life of a diesel school bus engine can easily exceed 20 years. To accelerate the transition to cleaner bus fleets, the agency and a number of states have sponsored voluntary programs to either replace pre-2007 buses or retrofit them with emission controls. Available control technologies include closed crankcase ventilation systems, diesel oxidation catalysts, and diesel particle filters. Controls can substantially reduce in-cabin exposures, although the profiles of emissions and exposure reductions vary between different technologies, used either singly or combination (11). In 2006, the U.S. Environmental Protection Agency mandated conversion to ultra-low-sulfur diesel (ULSD), leading to modest nationwide particulate matter emissions reductions. Adar and colleagues (9) took advantage of staggered implementation of mandated and voluntary controls in Seattle and Tacoma, Washington, to examine the effects on airway inflammation (measured as exhaled nitric oxide), growth in lung function, and school absenteeism among a sample of 275 public school bus riders aged 6–12 years, enriched in children with asthma.

Adar and colleagues found that adoption of ULSD, along with diesel oxidation catalysts, and/or closed crankcase ventilation systems, reduced fine and ultrafine particle concentrations inside buses by 10–50%. The switch to ULSD was associated with significant reductions in exhaled nitric oxide, growth in forced vital capacity, and lower absenteeism, with stronger associations among participants with asthma. Diesel oxidation catalysts and closed crankcase ventilation systems were also associated with improvements in these outcomes, but the findings were primarily restricted to children with persistent asthma, and the results were sensitive to inclusion of ULSD in the statistical models.

The strengths of this study include assessment of real-world interventions in a real-world setting, measurement of important health-related outcomes, and individual-level analysis of associations between the interventions and outcomes. With air pollution measurements during 597 trips on 188 school buses taken under actual conditions of use, this study has made a valuable contribution to the literature on exposures in school buses. To date, most studies have examined a small number of buses, often under simulated conditions of use (12). The exposure assessment was carefully designed with on-roadway pollution measured in a preceding vehicle to allow estimation of self-pollution. A prior study, also set in Seattle, had demonstrated reductions in absenteeism with retrofits at the school district level, but such group-level analyses are susceptible to ecological fallacy (13). Adar and colleagues (9) is the first study to examine the health effects of bus retrofits at the individual level.

Adar and colleagues (9) also make a valuable contribution to the evidence regarding the importance of short-term, relatively high-intensity exposures to TRAP and the benefits of controlling these exposures. Evidence regarding the health effects of commonly encountered "peak-level" exposures to TRAP has been limited. Short-term exposures to diesel exhaust have been associated with airway hyperreactivity and decrements in lung function among adults with asthma in controlled exposure and naturalistic settings (14, 15). Hourly peak exposures to particulate matter were associated with acute decrements in lung function among children with asthma in California (16).

Although the timing and type of intervention was linked to children at the individual level, not all buses were sampled, and individual-level exposures were not assigned, precluding direct assessment of associations between specific pollutants and the measured outcomes. The authors found that various assumptions about temporal factors did not alter the results, but they could not rule out secular changes in other outcome-related factors that might have confounded the observed associations.

Efforts to clean up diesel engine emissions from school buses are likely to have tremendous societal benefits. Adar and colleagues estimated that the nationwide switch to ULSD alone resulted in 14 million fewer absences per year. Greater benefits will accrue from fleet turnover to 2007 or later engines and continuing engine retrofit programs. In addition to lower in-cabin air pollution, these controls will reduce the diesel pollution that has been measured at bus stops, in school yards, and inside school buildings (17). Because school buses travel in residential areas in close proximity to people, we all stand to benefit from these efforts. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

Robert J. Laumbach, M.D., M.P.H
Department of Environmental and Occupational Medicine
Rutgers Robert Wood Johnson Medical School
Piscataway, New Jersey

and

Environmental and Occupational Health Sciences Institute
Rutgers University
Piscataway, New Jersey

References

1. Sabin LD, Behrentz E, Winer AM, Jeong S, Fitz DR, Pankratz DV, Colome SD, Fruin SA. Characterizing the range of children's air pollutant exposure during school bus commutes. *J Expo Anal Environ Epidemiol* 2005;15:377–387.
2. Laumbach RJ. Outdoor air pollutants and patient health. *Am Fam Physician* 2010;81:175–180.
3. Health Effects Institute. Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. Boston: Health Effects Institute; 2010 [accessed 2015 May 20]. Available from: http://pubs.healtheffects.org/getfile.php?u=553
4. Guarnieri M, Balmes JR. Outdoor air pollution and asthma. *Lancet* 2014; 383:1581–1592.

5. Grigg J. Traffic-derived air pollution and lung function growth. *Am J Respir Crit Care Med* 2012;186:1208–1209.
6. Jerrett M, Shankardass K, Berhane K, Gauderman WJ, Künzli N, Avol E, Gilliland F, Lurmann F, Molitor JN, Molitor JT, *et al*. Traffic-related air pollution and asthma onset in children: a prospective cohort study with individual exposure measurement. *Environ Health Perspect* 2008; 116:1433–1438.
7. Jerrett M, McConnell R, Wolch J, Chang R, Lam C, Dunton G, Gilliland F, Lurmann F, Islam T, Berhane K. Traffic-related air pollution and obesity formation in children: a longitudinal, multilevel analysis. *Environ Health* 2014;13:49.
8. Sunyer J, Esnaola M, Alvarez-Pedrerol M, Forns J, Rivas I, López-Vicente M, Suades-González E, Foraster M, Garcia-Esteban R, Basagaña X, *et al*. Association between traffic-related air pollution in schools and cognitive development in primary school children: a prospective cohort study. *PLoS Med* 2015;12:e1001792.
9. Adar SD, D'Souza J, Sheppard L, Kaufman JD, Hallstrand TS, Davey ME, Sullivan JR, Jahnke J, Koenig J, Larson TV, *et al*. Adopting clean fuels and technologies on school buses: pollution and health impacts in children. *Am J Respir Crit Care Med* 2015;191: 1413–1421.
10. Adar SD, Davey M, Sullivan JR, Compher M, Szpiro A, Liu LJS. Predicting airborne particle levels aboard Washington State school buses. *Atmos Environ (1994)* 2008;42:7590–7599.
11. Zhang Q, Zhu Y. Performance of school bus retrofit systems: ultrafine particles and other vehicular pollutants. *Environ Sci Technol* 2011; 45:6475–6482.
12. Borak J, Sirianni G. Studies of self-pollution in diesel school buses: methodological issues. *J Occup Environ Hyg* 2007;4:660–668.
13. Beatty TKM, Shimshack JP. School buses, diesel emissions, and respiratory health. *J Health Econ* 2011;30:987–999.
14. Hussain S, Laumbach R, Coleman J, Youssef H, Kelly-McNeil K, Ohman-Strickland P, Zhang J, Kipen H. Controlled exposure to diesel exhaust causes increased nitrite in exhaled breath condensate among subjects with asthma. *J Occup Environ Med* 2012;54:1186–1191.
15. McCreanor J, Cullinan P, Nieuwenhuijsen MJ, Stewart-Evans J, Malliarou E, Jarup L, Harrington R, Svartengren M, Han IK, Ohman-Strickland P, *et al*. Respiratory effects of exposure to diesel traffic in persons with asthma. *N Engl J Med* 2007;357:2348–2358.
16. Delfino RJ, Staimer N, Tjoa T, Gillen D, Kleinman MT, Sioutas C, Cooper D. Personal and ambient air pollution exposures and lung function decrements in children with asthma. *Environ Health Perspect* 2008;116:550–558.
17. Hochstetler HA, Yermakov M, Reponen T, Ryan PH, Grinshpun SA. Aerosol particles generated by diesel-powered school buses at urban schools as a source of children's exposure. *Atmos Environ (1994)* 2011;45:1444–1453.

Automated Digital Microscopy in New Tuberculosis Diagnostic Algorithms

Can It Boost Case Finding?

The World Health Organization (WHO) has recently launched its innovative End TB Strategy, supporting the vision of a tuberculosis (TB)-free world with zero death, disease, and suffering caused by TB (1, 2), as well as the concept of TB elimination (3, 4).

The new strategy clearly supports universal access to quality TB diagnosis and treatment, on top of a new vaccine. In the last couple of years, the TB diagnostic armamentarium has been substantially strengthened by the introduction of the Xpert MTB/RIF assay (Cepheid, Sunnyvale, CA) (5). This test demonstrated high sensitivity (89% in pulmonary TB, being close to 100% in sputum smear-positive and 68% in sputum smear-negative patients) and specificity (99%) for detecting TB compared with culture (5, 6). In addition, the Xpert MTB/RIF assay showed a pooled sensitivity and specificity of 95% and 98%, respectively, for detecting resistance to rifampicin (6), which is presently the core anti-TB drug (7–9). The test, which is easy to perform, provides a result in less than 2 hours, allowing prompt clinical action while waiting for culture and drug susceptibility testing. For the first time, after more than a century, we can replace smear examination as the first diagnostic test for TB diagnosis.

Unfortunately, in spite of the efforts of the international community (6.2 million Xpert MTB/RIF tests were performed between 2011 and 2014) (10), it is unlikely that more than 10% of the patients with presumptive TB have access to this test globally (11). Although the cost of this test has significantly decreased in the last years (to $9.98 per cartridge) (12), it is still considerably higher than that of sputum smear microscopy (11). This is why in several low-income countries, TB diagnosis still relies mostly on sputum microscopy (11).

While the accessibility of the Xpert test is being expanded to all patients with presumptive TB worldwide, efforts also have been made to develop diagnostic algorithms able to reduce the number of tests performed in field conditions and to ensure adequate sensitivity in detecting TB cases.

The algorithm proposed in this issue of the *Journal* by Ismail and colleagues (pp. 1443–1449), from South Africa, is interesting (13). It is based on the automated digital microscopy (TBDx automated system). This promising new technology is able to process digital microscope images to identify alcohol acid-fast bacilli (AFB), whose performance, within a properly designed diagnostic algorithm, have not been formally tested. Ismail and colleagues evaluated the performance of the new diagnostic tool by processing 1,210 samples from a prospective cohort of patients with presumptive TB, in parallel with conventional sputum smear microscopy and liquid culture. The specimens that resulted positive for TB with the new diagnostic underwent Xpert MTB/RIF evaluation. The authors calculated sensitivity and specificity of the two algorithms, using either the new test followed by Xpert for the "low-positive" samples (one to nine putative AFB) only, or the new test alone in comparison with liquid culture. Of the 1,009 samples eligible for evaluation, 109 yielded a positive *Mycobacterium tuberculosis* culture.

The new diagnostic resulted in 70 specimens (68 culture-positive) having $\geqslant$10 putative AFB (high positivity) and 207 specimens (19 culture-positive) having one to nine putative AFB (low positivity). In the algorithm in which "low-positive" results on the new diagnostic were confirmed by Xpert, the sensitivity was 78% (85/109) and the specificity 99.8% (889/900). With the new test followed by Xpert, only 21% of the Xpert tests otherwise needed (207/1009) would be used, with significant savings. Using the new test alone, the new diagnostic yielded 62% sensitivity and 99.7% specificity.

ORIGINAL ARTICLE

Adopting Clean Fuels and Technologies on School Buses
Pollution and Health Impacts in Children

Sara D. Adar[1], Jennifer D'Souza[1], Lianne Sheppard[2,3], Joel D. Kaufman[2,4,5], Teal S. Hallstrand[4], Mark E. Davey[6], James R. Sullivan[2], Jordan Jahnke[7], Jane Koenig[2], Timothy V. Larson[2,8], and L. J. Sally Liu[2,6†]

[1]Department of Epidemiology, University of Michigan, Ann Arbor, Michigan; [2]Department of Environmental and Occupational Health Sciences, [3]Department of Biostatistics, [4]Department of Medicine, and [5]Department of Epidemiology, University of Washington, Seattle, Washington; [6]Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Basel, Switzerland; [7]Department of Biostatistics, University of Michigan, Ann Arbor, Michigan; and [8]Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington

Abstract

Rationale: More than 25 million American children breathe polluted air on diesel school buses. Emission reduction policies exist, but the health impacts to individual children have not been evaluated.

Methods: Using a natural experiment, we characterized the exposures and health of 275 school bus riders before, during, and after the adoption of clean technologies and fuels between 2005 and 2009. Air pollution was measured during 597 trips on 188 school buses. Repeated measures of exhaled nitric oxide (F_{ENO}), lung function (FEV_1, FVC), and absenteeism were also collected monthly (1,768 visits). Mixed-effects models longitudinally related the adoption of diesel oxidation catalysts (DOCs), closed crankcase ventilation systems (CCVs), ultralow-sulfur diesel (ULSD), or biodiesel with exposures and health.

Measurements and Main Results: Fine and ultrafine particle concentrations were 10–50% lower on buses using ULSD, DOCs, and/or CCVs. ULSD adoption was also associated with reduced F_{ENO} (−16% [95% confidence interval (CI), −21 to −10%]), greater changes in FVC and FEV_1 (0.02 [95% CI, 0.003 to 0.05] and 0.01 [95% CI, −0.006 to 0.03] L/yr, respectively), and lower absenteeism (−8% [95% CI, −16.0 to −0.7%]), with stronger associations among patients with asthma. DOCs, and to a lesser extent CCVs, also were associated with improved F_{ENO}, FVC growth, and absenteeism, but these findings were primarily restricted to patients with persistent asthma and were often sensitive to control for ULSD. No health benefits were noted for biodiesel. Extrapolating to the U.S. population, changed fuel/technologies likely reduced absenteeism by more than 14 million/yr.

Conclusions: National and local diesel policies appear to have reduced children's exposures and improved health.

Keywords: particulate matter; air pollution; asthma; absenteeism; lung function

Traffic-related air pollution may adversely affect children's respiratory health (1–11). Little is known, however, about the health effects of commuting to school, especially aboard diesel-powered school buses. As more than 25 million American children commute via school bus (12) and experience elevated pollution levels on these buses (13–19), commuting is a major contributor to children's exposures to traffic-related air pollutants (14, 20–22).

To limit exposures to diesel exhaust and to protect health, the U.S. Environmental Protection Agency (USEPA) created a voluntary retrofit initiative to help states install clean air technologies on vehicles. Clean air technologies such as

(Received in original form October 29, 2014; accepted in final form April 9, 2015)

†Deceased.

Supported by the NIEHS (#1R01ES12657-01A1), the Washington Department of Ecology, and the University of Washington Center for Ecogenetics and Environmental Health (NIEHS, P30ES007033).

Author Contributions: S.D.A., L.S., J.D.K., T.S.H., M.E.D., J.K., and L.J.S.L. were involved in the study design of this project. S.D.A., T.S.H., M.E.D., J.R.S., and L.J.S.L. were involved in data collection. S.D.A., J.D'S., L.S., and J.J. were involved in data analysis. S.D.A., L.S., J.D.K., T.S.H., J.K., L.J.S.L., and T.V.L. were involved in data interpretation. S.D.A. wrote the first draft of the manuscript with feedback from all authors but L.J.S.L., who died before completion of the manuscript.

Correspondence and requests for reprints should be addressed to Sara D. Adar, Sc.D., Department of Epidemiology, University of Michigan, 1415 Washington Heights, SPHII-5539, Ann Arbor, MI 48109. E-mail: sadar@umich.edu

This article has an online supplement, which is accessible from this issue's table of contents at www.atsjournals.org

Am J Respir Crit Care Med Vol 191, Iss 12, pp 1413–1421, Jun 15, 2015

Originally Published in Press as DOI: 10.1164/rccm.201410-1924OC on April 13, 2015
Internet address: www.atsjournals.org

At a Glance Commentary

Scientific Knowledge on the Subject: Exposures to traffic-related air pollution at home and school have been repeatedly linked to adverse respiratory health in children. Children also experience elevated pollution levels on diesel-powered school buses, yet little is known about the resultant health effects or the level of protection offered by clean air technologies and fuels on school buses.

What This Study Adds to the Field: The findings from this natural experiment suggest that when children ride buses with clean air technologies and/or fuels, they experience lower exposures to air pollution, less pulmonary inflammation, more rapid lung growth over time, and reduced absenteeism than when they are on buses without these technologies and fuels. These improvements were often strongest among children with asthma, suggesting that cleaner buses may be especially important to protecting the health of our most vulnerable students. Given that more than 25 million American children commute to school each day via school bus, these findings have clear policy implications for protecting the health of school children.

diesel oxidation catalysts (DOCs) and crankcase ventilation systems (CCVs) are used to reduce tailpipe and engine emissions, respectively. These technologies, which can be adopted on older buses and are commonly installed on newer buses, are estimated to reduce particulate emissions and onboard concentrations by 20 to 50% (23–28). The USEPA also required that refineries produce ultralow-sulfur diesel (ULSD) starting in 2006 under the Highway Diesel Fuel Sulfur Control Requirements. ULSD and biodiesel are projected to reduce particle generation by approximately 10–30% and to enhance the operation of clean air technologies (23, 29). Although these initiatives have been estimated to prevent approximately 20,000 hospitalizations and 3.3 million days of lost productivity (30), no study has directly assessed the health impacts of these policies on individual children.

We investigated the impacts of clean air technologies and fuels on air pollution levels in school buses and on pulmonary health in a cohort of elementary school children. Associations were explored using a natural experiment in which we monitored in-bus air pollution concentrations and markers of health before, during, and after the staggered adoption of clean air technologies and fuels. Early results of this study have been previously reported as abstracts (31–33), and one published article (16).

Methods

Population and Design

We sampled 307 school bus riders (6–12 yr) attending a public elementary school in the Seattle and Tahoma, Washington, school districts (*see* Figure E1 in the online supplement). Children were monitored monthly (2005–2009) while the Puget Sound Clean Air Agency (PSCAA) incentivized clean air technology installation and a fuel change occurred under USEPA rules. Children were unaware of the technology and fuel of their buses, resulting in a blinded natural experiment with the collection of exposure and health measurements before, during, and after the staggered implementation of interventions. Children with asthma were preferentially recruited for power and as a sensitive subpopulation (34). Children in smoking households, on buses with fewer than 50 seats, taking oral corticosteroids, or missing information were excluded, resulting in a sample of 275. All protocols were approved by our institutional review board and written guardian consent and child assent were obtained.

Bus Characteristics

Children's buses were identified on the basis of information from the district transportation departments and later confirmed by school administrators and study technicians. When children rode more than one bus, we used their primary bus for our analyses. Bus characteristics, including age, mileage, technologies, and fuels, were compiled from the PSCAA, school transportation departments, and annual inspection. Adoption of clean air technologies and fuels was also tracked continuously with a focus on DOCs, CCVs, ULSD, and a biodiesel mixture (approximately 20%). Although we had also been interested in diesel particulate filters (DPFs), these were used only temporarily on five buses, so we had insufficient information for our models.

Air Pollution

We collected measurements inside 188 buses ("in cabin") during 597 regular commutes greater than 10 minutes. Fine ($PM_{2.5}$) and ultrafine (UFP) particulate matter were measured with a *p*DR-1200 equipped with a cyclone preseparator (Thermo Scientific, Waltham, MA) and P-TRAK 8525 (TSI, Shoreview, MN), respectively. A PAS2000CE (EcoChem Analytics, League City, TX) was also used to capture particle-bound polycyclic aromatic hydrocarbons (pb-PAHs) as well as the black carbon content of the particles. During most trips, pollution was also measured inside a gasoline hybrid electric car traveling before the bus with open windows ("on road"). Differences between the bus and road reflect the pollution from the bus itself ("self-pollution") as has been validated by chemical tracer research (35). Ambient pollution measurements were also obtained from the PSCAA.

Pulmonary Health

Lung function and exhaled nitric oxide ($F_{E_{NO}}$) were measured monthly at school by technicians unaware of the children's bus characteristics. Measurements were collected at fixed times on school day mornings and afternoons, in accordance with standard procedures (36). $F_{E_{NO}}$ and room nitric oxide were collected with an offline collection kit (Sievers, Boulder, CO). Children exhaled into 1.5-liter aluminized Mylar balloons at a constant pressure of 12 cm H_2O to prevent contamination by nasal nitric oxide and to normalize expiratory flow rates. $F_{E_{NO}}$ samples were collected in triplicate and analyzed within 4 hours with an NOA 280i (Sievers), using the median value for our analysis. FEV_1 and FVC were measured with a MicroDL spirometer (Micro Medical, Lewiston, ME). Self-reported absenteeism in the previous month was supplemented with technician-collected records on absenteeism on the day of health testing.

General health, including asthma symptoms and recent illness, was ascertained by technician-administered questionnaires. Asthma status was assessed annually by doctor diagnosis or symptoms of wheezing or whistling in chest, wheezing after exercise, or a dry cough at night over the previous year based on validated questions

from the International Study of Asthma and Allergies in Childhood (ISAAC) survey (37). Asthma severity was defined as persistent asthma (on controller medication), intermittent asthma (not on controller medication), and nonasthmatic.

Covariates

Self-reported demographics (race, sex, parental education) and medical history were collected at an annual health screening. Height and weight were obtained during monthly examinations, concurrent with collection of pulmonary health endpoints. Meteorology (relative humidity and temperature) and flu prevalence data were obtained from the University of Washington Atmospheric Sciences Department and the U.S. Influenza-Like Illness Surveillance Network, respectively. School and home locations were classified as near a major roadway, using ArcGIS (ESRI, Redlands, CA), if they were within 100 m of an interstate or U.S. highway or within 50 m of a state or county highway.

Statistical Analysis

Descriptive statistics were generated using repeated-measures analysis of variance models. Exploratory analyses then compared pollution and health between buses that never or always had certain technologies/fuels as well as within buses before and after a switch. Pollutant and Fe_{NO} levels were log-transformed due to right-skewed distributions and investigated using multivariable mixed-effects models to account for correlation between repeated measures. Two-stage growth models with random intercepts and slopes were used for spirometry measures (38, 39). Risk differences for being absent within the past month were modeled with a mixed-effects log binomial regression. In-bus pollution models adjusted for ambient $PM_{2.5}$, weather (wind speed, temperature, relative humidity), bus characteristics (manufacturer, mileage, year, engine position, make, and model, bus base), and trip covariates (stops, duration, window usage, time of day, on-road pollution events). Health models were adjusted for age, race, sex, asthma, temperature, relative humidity, ambient $PM_{2.5}$, district flu prevalence, and seasonality. For Fe_{NO} and spirometry, height, weight, and cold/flu were also included. School air nitric oxide and day of week were included in Fe_{NO} models. Nonlinear relationships were assessed in R version 3.02 (www.r-project.org) and modeled with splines (flu prevalence) whereas other analyses used SAS version 9.3 (SAS Institute, Cary, NC). Models were run first with individual technologies and fuels and then with all technologies and fuels to separate the independent associations with pollutants and health. We further explored the impacts of DOC, CCV, and biodiesel among buses after the national switch to ULSD to assess the added benefit of nonrequired clean air interventions.

We tested for effect modification by asthma status and confirmed the robustness of our results to control for parental education, school/home roadway proximity, district, and additional time trends. We also explored sensitivity to classifying asthma on the basis of doctor diagnosis, restricting to children riding the same bus at least 75% of the time, control for or exclusion of buses with a DPF, and using fixed-effects models. Finally, we estimated preventable absences if all American school bus riders exclusively rode buses with clean air technologies and fuels. These calculations assumed that 54.6% of 54,876,000 school children ride buses (12), that 9.3% of these children have asthma (40), and that, of the children with asthma, 25% have persistent asthma (41).

Results

Study Participants

A total of 275 bus riders provided 3,223 observations with an average of 6 (range, 1–19) repeat visits over 4 years. These children were predominantly white and from college-educated families (Table 1). The mean age was 9.5 years. More than half (54%) were asthmatic, and the majority (85%) were not taking controller medication. Higher Fe_{NO} levels, more frequent absenteeism, and lower baseline lung function were observed among children with asthma compared with healthy children.

Buses Serving Study Population

During our 4-year study the adoption of clean air technologies and fuels increased over time (Figure 1). Across all buses serving our study population, approximately half had DOCs and ULSD and 35% had CCVs in the first year whereas greater than 90% had these technologies and fuels in the final year. This resulted in the majority of students always riding buses with DOCs (69%) and ULSD (81%) and fewer always riding buses with CCV (34%) and biodiesel (7%). Between 15 and 37% of students rode buses with and without clean air technologies and/or fuels, allowing for within-subject comparisons (Table 1 and Table E1). In general, there was little correlation between the various technologies and fuels, with the exception of DOC and ULSD, which had a correlation of approximately 0.5.

Measured Pollution Levels on Monitored Buses

Among the 597 trips on 188 buses with air pollution monitoring, the average mileage was 65,100 (SD, 58,700) and bus body year was 2002 (SD, 5) (Table 2). The average trip had a duration of 40 minutes (SD, 17 min) with 27 riders (SD, 14). Mean (±SD) in-cabin $PM_{2.5}$ concentrations (20 ± 18 $\mu g/m^3$) were approximately three times higher than ambient levels (7 ± 5 $\mu g/m^3$) and 1.5 times higher than roadway levels (13 ± 12 $\mu g/m^3$). Mean in-cabin UFP levels (21 ± 12 thousand/cm^3) were lower than on the surrounding roadways (29 ± 20 thousand/cm^3). Average pb-PAH concentrations were also lower inside bus cabins (101 ± 70 ng/m^3) than on surrounding roadways (125 ± 88 ng/m^3).

In multivariable models, we found strong evidence of lower in-cabin $PM_{2.5}$ concentrations with clean air technology use but weaker evidence for fuel types (Figure 2). DOCs and CCVs were associated with 26% (95% CI, −42 to −6%) and 40% (95% CI, −48 to −30%) lower in-cabin $PM_{2.5}$ concentrations, respectively. In contrast, UFPs were lowest with DOCs (−43%; 95% CI, −53 to −31%) and ULSD (−47%; 95% CI, −58 to −34%) with weaker reductions for CCVs and no associations with biodiesel. For pb-PAH concentrations, there were consistent increases with DOCs, CCVs, and ULSD. Only biodiesel was associated with lower in-cabin pb-PAH concentrations (−40%; 95% CI, −49 to −28%). Findings were similar for self-pollution concentrations and models adjusted for other technologies and fuels (results not shown).

Exhaled Nitric Oxide

Strong and statistically significant associations were identified between Fe_{NO} and ULSD use in fully adjusted models (Figure 3). Among the whole cohort, ULSD was associated with 16% (95% CI, −21 to −10%) lower Fe_{NO} levels. These

Table 1. Characteristics of Bus-Riding Elementary School Children Monitored between 2005 and 2009 during the Adoption of Clean Air Technologies and Fuels

	All	No Asthma	Intermittent Asthma	Persistent Asthma
Number of children	275 (100%)	126 (46%)	126 (46%)	23 (8%)
Number of samples	3,223 (100%)	1,590 (49%)	1,326 (41%)	307 (10%)
Baseline age, yr				
6–8	90 (33%)	34 (27%)	47 (37%)	9 (39%)
9–10	127 (46%)	65 (52%)	52 (41%)	10 (43%)
11–12	58 (21%)	27 (21%)	27 (21%)	4 (17%)
Female	124 (45%)	57 (45%)	58 (46%)	9 (39%)
Race				
Asian	25 (9%)	11 (9%)	13 (10%)	1 (4%)
Black	23 (8%)	4 (3%)	18 (14%)	1 (4%)
Other	19 (7%)	5 (4%)	9 (7%)	5 (22%)
White	203 (74%)	105 (83%)	83 (66%)	15 (65%)
Parental education				
College	33 (12%)	8 (6%)	22 (17%)	3 (13%)
Some college	35 (13%)	16 (13%)	16 (13%)	3 (13%)
College	88 (32%)	45 (36%)	32 (25%)	11 (48%)
College	105 (38%)	54 (43%)	45 (36%)	6 (26%)
School district				
Tahoma	89 (32%)	39 (31%)	39 (31%)	11 (48%)
Seattle	186 (68%)	87 (69%)	87 (69%)	12 (52%)
Height, m	1.4 (0.1)	1.4 (0.1)	1.4 (0.1)	1.4 (0.2)
Weight, kg	35.2 (11.0)	34.2 (9.1)	36.2 (12.1)	34.6 (14.1)
Outcomes				
$F_{E_{NO}}$, ppb	12.1 (1.9)	10.0 (1.6)	14.2 (2.0)	14.3 (2.3)
FEV_1, L				
Baseline	1.73 (0.4)	1.78 (0.36)	1.69 (0.42)	1.67 (0.47)
Δ per year	0.13 (0.49)	0.15 (0.4)	0.14 (0.51)	0.01 (0.77)
FVC, L				
Baseline	2.09 (0.48)	2.13 (0.45)	2.06 (0.49)	2.09 (0.54)
Δ per year	0.17 (0.54)	0.2 (0.38)	0.2 (0.57)	−0.06 (0.94)
MMEF, cl/s				
Baseline	167.0 (56.1)	176.2 (52.5)	160.5 (58.2)	152.3 (58.2)
Δ per year	14.5 (121.1)	14.4 (113.5)	14.8 (125.7)	12.9 (141.4)
Missed school days per month	0.35 (0.25)	0.32 (0.25)	0.35 (0.26)	0.40 (0.24)
Interventions				
DOC				
Never	36 (13%)	19 (15%)	15 (15%)	2 (9%)
Sometimes	48 (17%)	23 (18%)	18 (18%)	7 (30%)
Always	191 (69%)	84 (67%)	93 (67%)	14 (61%)
CCV				
Never	81 (29%)	37 (29%)	36 (29%)	8 (35%)
Sometimes	101 (37%)	52 (41%)	41 (33%)	8 (35%)
Always	93 (34%)	37 (29%)	49 (39%)	7 (30%)
ULSD				
Never	13 (5%)	8 (6%)	5 (4%)	0 (0%)
Sometimes	40 (15%)	18 (14%)	15 (12%)	7 (30%)
Always	222 (81%)	100 (79%)	106 (84%)	16 (70%)
Biodiesel				
Never	183 (67%)	90 (71%)	77 (61%)	16 (70%)
Sometimes	72 (26%)	32 (25%)	38 (30%)	2 (9%)
Always	20 (7%)	4 (3%)	11 (9%)	5 (22%)

Definition of abbreviations: CCV = crankcase ventilation system; DOC = diesel oxidation catalyst; $F_{E_{NO}}$ = fraction of exhaled nitric oxide; MMEF = maximal midexpiratory flow; ULSD = ultralow-sulfur diesel.
Data are given as n (%) or mean (SD).

associations were strongest among children with asthma: 31% (95% CI, −39 to −21%), 20% (95% CI, −28 to −12%), and 6% (95% CI, −14 to 2%) lower levels among children with persistent asthma, intermittent asthma, and no asthma, respectively. These associations were robust to control for other technologies and fuels (results not shown).

For children with persistent asthma, lower $F_{E_{NO}}$ levels were observed for children riding buses with DOCs (−12%; 95% CI, −23 to −0.4%) or CCVs (−14%; 95% CI, −24 to −4%) compared with buses without these technologies. Associations with CCVs, but not DOCs, were robust to control for other technologies and fuels but they were not

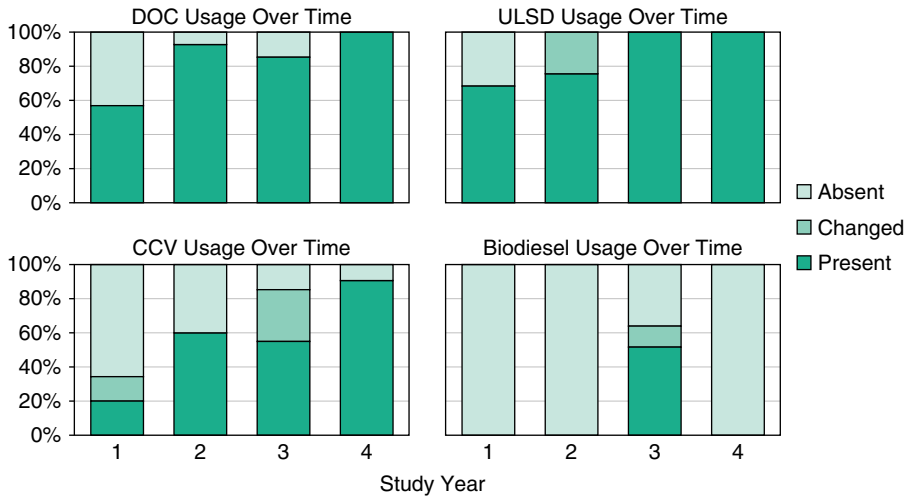

Figure 1. Clean air technologies and fuels over the 4-year study (defined as absent all year, changed during the year, or present all year). CCV = crankcase ventilation system; DOC = diesel oxidation catalyst; ULSD = ultralow-sulfur diesel.

found among other children. Biodiesel was unassociated with F_{ENO}.

Pulmonary Function

Among all children, rates of change were 0.17 L/yr for FVC and 0.13 L/yr for FEV_1. After control for other factors, we observed 0.02 (95% CI, 0.003–0.05) and 0.02 (95% CI, 0.001–0.04) L/yr faster rates of change in FVC among children riding buses with ULSD and DOCs, respectively (Figure 4). These associations with FVC were generally robust to control for other technologies and fuels as well as stratification by school year among children without asthma (results not shown). Suggestive increases in FEV_1 over time were also found among all children for ULSD (0.01 L/yr; 95% CI, −0.006 to 0.03) and DOC (0.01 L/yr; 95% CI, −0.008 to 0.03) use, due primarily to associations with children without asthma and those with mild asthma. Lower changes in FEV_1 were observed with DOCs, ULSD, and biodiesel among those with persistent asthma. Although these associations were generally robust to control for multiple interventions, they had wide confidence intervals and could not be distinguished from no association.

Table 2. Characteristics of Monitored School Buses and Trips

	All Buses		Buses That Switched Technologies/Fuels	
	Buses	Trips	Buses	Trips
n	188	597	62	292
Clean air technologies*				
Diesel oxidative catalyst	165 (88%)	510 (85%)	18 (29%)	93 (32%)
Crankcase ventilation	134 (71%)	376 (63%)	36 (58%)	177 (61%)
Diesel particulate filter	5 (3%)	10 (2%)	0 (0%)	0 (0%)
Clean air fuels*				
Ultralow-sulfur diesel	183 (97%)	549 (92%)	18 (29%)	93 (32%)
Biodiesel	59 (31%)	152 (25%)	28 (45%)	138 (47%)
Mileage, in thousands	65.7 (57.4)	65.1 (58.7)	70.1 (54.5)	71.3 (58.9)
Body year	2002 (5.2)	2002 (5.0)	2002 (4.7)	2002 (4.7)
Seating capacity	72 (4.4)	72 (4.5)	73 (4.0)	73 (4.1)
Opacity, %	4 (7.3)	5 (9.8)	5 (7.9)	5 (9.6)

Data are given as n (%) or mean (SD).
*Bus results reported if bus ever had the technology or fuel. Trip data reflect the conditions during the monitoring event.

Absenteeism

Children missed an average of 3.1 school days over 9 months (2.9 for children without asthma, 3.6 for children with persistent asthma). Among all children, there was an 8% (95% CI, −16 to −1%) lower risk of being absent in the previous month when riding a bus with ULSD as compared with other buses (Figure 5). Similar findings were observed for DOC use: a 6% (95% CI, −11 to −0.2%) reduction in the risk of absenteeism over the past month. These associations were largest among children with asthma, especially those receiving controller therapy. Although associations with ULSD were robust to control for other technologies and fuels, associations with DOCs were diminished by control for ULSD (results not shown). On the basis of these findings, we estimate that the switch to ULSD resulted in 14 million fewer absences per year across the United States.

Sensitivity of Results

Associations between clean air technologies and fuels with each of the health endpoints were qualitatively robust to further adjustment for parental education, school/home proximity to major roads, district, and additional time trends. Our findings were also insensitive to use of doctor-diagnosed asthma, restricting to children riding the same bus at least 75% of the time, excluding or controlling for buses with a DPF, and modeling using fixed effects. Restriction to only those buses using ULSD suggested independent improvements with DOCs for absenteeism among children with severe asthma and changes in FVC over time, although little change was observed with FEV_1 or F_{ENO} after this restriction (results not shown).

Discussion

In this natural experiment, we documented lower in-vehicle exposures and improved pulmonary health of children with the adoption of clean air technologies and fuels on school buses. $PM_{2.5}$ concentrations were 25–40% lower on buses with DOCs and CCVs, and UFP levels were 40–50% lower on buses with DOCs and ULSD. In health analyses, we found that ULSD was most consistently associated with beneficial effects with evidence of less pulmonary inflammation, faster lung growth, and lower risks of school absenteeism. These

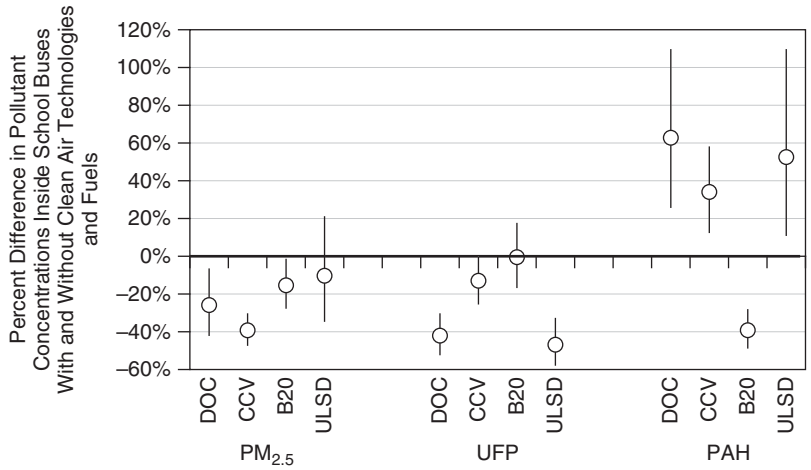

Figure 2. Associations of clean air technologies and fuels with air pollution concentrations inside school buses after control for ambient weather and pollutants, bus characteristics, and trip features. Models were adjusted for ambient wind speed, temperature, relative humidity, ambient $PM_{2.5}$, noted pollution events, trip duration, number of stops, open windows, time of day, bus base, year bus was built, mileage, engine make and model, body make, and random intercept for each bus. These contrasts include data from different buses and those that switched technologies. B20 = biodiesel; CCV = crankcase ventilation system; DOC = diesel oxidative catalyst; PAH = polycyclic aromatic hydrocarbons; $PM_{2.5}$ = fine particulate matter, ⩽2.5-μm diameter; UFP = ultrafine particulate matter; ULSD = ultralow-sulfur diesel.

results were robust to control for other technologies and fuels and were often largest among children with asthma, especially those with persistent asthma. DOCs, and to a lesser extent CCVs, also were associated with better health, but these findings were primarily restricted to those with persistent asthma and were often sensitive to control for ULSD. Overall, we found that adopting certain clean air technologies and fuels reduced in-vehicle particulate exposures and likely improved respiratory health.

To our knowledge, no prior studies have examined the individual-level health impacts of clean air technologies and fuels, although one school district–level analysis suggested that a school bus emission reduction program was associated with decreased incidence of bronchitis, asthma, and pneumonia (42). Our findings suggest that the benefits of school bus emission reductions are also experienced at the child level. We identified sizeable improvements in absenteeism for children riding buses with ULSD that are comparable to 50–70% of the reductions observed for children living in nonsmoking homes as compared with homes with smokers (43). With 25 million children riding buses to school (12), we estimate that switching to ULSD resulted in 14 million fewer absences per year in the United States. Such reductions in absenteeism may translate to improved grades and health for the students (15, 16) as well as less missed work and lost productivity for their caregivers. Although results were strongest with ULSD, we also found evidence of reduced absenteeism among children with severe asthma and increased FVC over time with DOC usage even when restricted to buses using ULSD. This suggests that there may be additional benefit to clean air technologies independent of any changes in fuel.

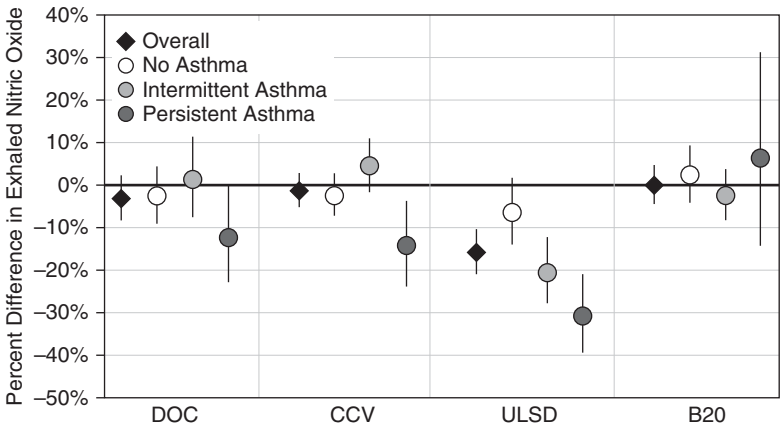

Figure 3. Adjusted associations (percent difference, 95% confidence interval) between levels of exhaled nitric oxide and clean air technologies and fuels among all students and by asthma status. Models were adjusted for age, sex, race/ethnicity, height, asthma status, ambient temperature, relative humidity, fine particulate matter (⩽2.5-μm diameter), room nitric oxide, district flu prevalence, individual report of a cold or flu, within–school year time trend, time of day, and random subject effect. B20 = biodiesel; CCV = crankcase ventilation system; DOC = diesel oxidative catalyst; ULSD = ultralow-sulfur diesel.

Clean air technologies and fuels were not only associated with health benefits but also with reductions in on-board pollution. Both DOC and CCVs showed significant reductions in $PM_{2.5}$ and UFPs. This is generally consistent with previous in-vehicle studies, which found reductions of 25–60% for $PM_{2.5}$ and 5–70% for UFPs (17, 25, 27, 28). Reductions in UFPs, and to a lesser extent $PM_{2.5}$, with ULSD are also consistent with an earlier in-cabin study using ULSD in combination with DPF (17). Interestingly, our findings of comparatively larger reductions in $PM_{2.5}$ with CCVs and larger reductions in UFPs with DOCs are supported by previous research demonstrating that in-cabin $PM_{2.5}$ concentrations are primarily due to crankcase emissions and that UFPs primarily originate from the tailpipe (35, 44). Although we have previously demonstrated distinct patterning of pb-PAHs from $PM_{2.5}$ and UFPs in school buses (45), the observed increase in pb-PAHs with DOCs, CCVs, and ULSD is unexpected given that past research has generally shown reductions with clean air technologies and fuels (17, 46–48). Unfortunately, we have little explanation for these findings. One hypothesis is that a shift in the distribution of PAHs between the gaseous and particle phase may have led to measurement artifact because enhanced

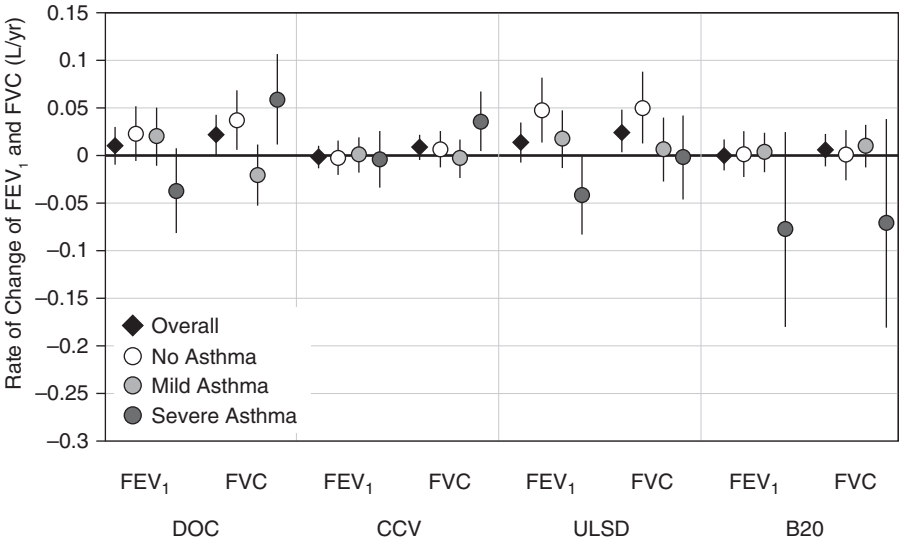

Figure 4. Adjusted associations (percent difference, 95% confidence interval) between rate of change in lung function over time and clean air technologies and fuels among all students and by asthma status. Models were adjusted for age, sex, race/ethnicity, height, weight, asthma status, ambient temperature, relative humidity, fine particulate matter (≤2.5-μm diameter), district flu prevalence, individual report of a cold or flu, within–school year time trend, and random subject effect. B20 = biodiesel; CCV = crankcase ventilation system; DOC = diesel oxidative catalyst; ULSD = ultralow-sulfur diesel.

nitro-PAH formation and nucleation can occur with clean air technologies (46, 49, 50).

The finding that ULSD and DOCs were most strongly and consistently associated with health suggests that UFPs may be a critical exposure on school buses. This is not surprising because UFPs are hypothesized to be especially toxic because of their high deposition in the lower airways, large surface areas to absorb chemicals/free radicals, lower removal by alveolar macrophages, and ability to initiate inflammation (51). Associations with F_{ENO}, a marker of cytokine activity in the airways and alveoli (52), also suggest that lowered inflammation is a likely mechanism through which decreased exposures may lead to improved health. Furthermore, our finding of greater health improvements among children with asthma is also consistent with UFPs because airway narrowing increases the deposition efficiency of UFP in the lungs (53).

The cohesiveness of our findings across several endpoints further supports the hypothesized benefits of clean air technologies and fuels on respiratory health. Our results are consistent with controlled exposure studies in animals and humans, which have reported increased inflammation after the inhalation of diesel exhaust (54–58). Given that ULSD, DOCs, and CCVs were associated with lower particulate concentrations, our results are further supported by population-based studies of children that have linked higher particulate concentrations with higher F_{ENO} (59, 60), slower lung growth (61, 62), asthma exacerbation (63), and school absenteeism (61, 64–66). Although all of our results were on the same order of magnitude as past research, our lung growth findings were somewhat larger than expected (61, 64–67). This may be partially attributable to the young age of this population or the high asthma prevalence because some, although not all, research has reported enhanced associations among this group (34).

This study has numerous strengths including its large size and repeated, individual-level health and in-vehicle air pollution measurements surrounding the adoption of clean air technologies and fuels. It is not, however, without limitations. One key limitation is the possibility for residual confounding by time because some technologies/fuels, like ULSD, were used only in the later years of the study. If our statistical models inadequately captured any temporal trends in health, then we could incorrectly attribute some of the observed changes in health to the bus technologies/fuels. Sensitivity analyses indicated that this was unlikely for F_{ENO} and absenteeism as our models were robust to additional adjustment for time and there were no significant time trends among children who rode buses that did not change technologies or fuels. In contrast, FVC is more closely linked to time in this population. We allowed for different growth curves by age and age-adjusted height after accounting for differences between the sexes, ages, and asthma status. Within this age range, linear trends are expected and observed. If, however, accelerated growth due to puberty occurred among a small fraction of children, then the true associations with lung growth could be overestimated. Another limitation is that our absenteeism information was not verified by school records. Any misclassification would not likely be differential, however, because children were unaware of their bus characteristics. In addition, we supplemented self-reported absenteeism data with technician-recorded absenteeism of children during their monthly examinations to account for the inherent problem that absent children cannot report their absenteeism. Finally, although we

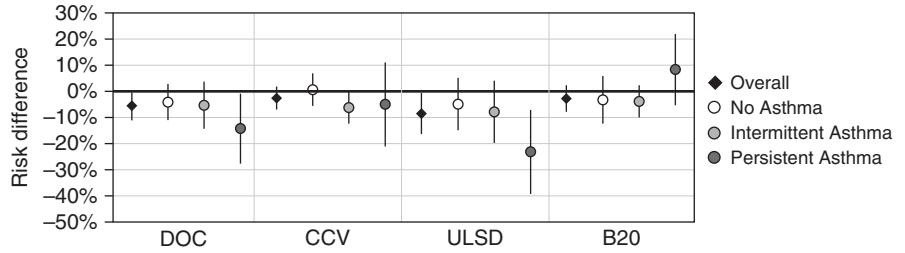

Figure 5. Adjusted associations (risk difference, 95% confidence interval) for any absenteeism in the past month as a function of clean air technologies and fuels among all students and by asthma status. Models were adjusted for age, sex, race/ethnicity, asthma status, ambient temperature, relative humidity, fine particulate matter (≤2.5-μm diameter), district flu prevalence, within–school year time trend, and random subject effect. B20 = biodiesel; CCV = crankcase ventilation system; DOC = diesel oxidative catalyst; ULSD = ultralow-sulfur diesel.

a priori anticipated that children with asthma would be more sensitive to exposures, we cannot exclude the possibility that our findings of enhanced associations among those with persistent asthma were due to chance given the small sample size (23 children, 307 samples).

In summary, we used a natural experiment to examine associations between clear air technologies and fuels in school buses and children's health. Our results show that the national switch to ULSD fuel may have had a measureable positive public health impact on children riding diesel school buses. This benefit was likely especially important for children with asthma. Our results further suggest that children with asthma may also have benefited from the nationwide voluntary school bus retrofit initiative and the adoption of DOCs and CCVs. Although the exact results varied by outcome, ULSD and DOCs were most consistently associated with both reduced pollutant concentrations and improved health, suggesting a role for UFPs in the health effects of diesel-powered school buses. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

Acknowledgment: This work would not have been possible without the efforts of René Irish, Erin Corwine, Nichole Real, Tim Gould, Alex Ineichen, and the Diesel Bus Monitoring Team. The authors are thankful for the advice and support of Dr. Jim Krieger (Seattle-King County Department of Public Health), Michael Boyer and David Adler (Department of Ecology), Bridget Anderson, Michelle Zaleski, Doug Sander, and Bruce Zahradnik (Tahoma Schools), Jill Lewis (Seattle Schools), Stacy Roberts, Robert Cook, and David Oylear (First Student), and Michael Montgomery (Curtis Transportation). The authors are also extremely grateful for collaborations with Joellen Lewtas (University of Washington), David Anderson (Seattle Schools Transportation Department), and Paul Carr and John Anderson (PSCAA Diesel Solution Program). The authors also thank the Seattle and Tahoma principals, teachers, and students whose daily support made this study possible.

References

1. Brunekreef B, Janssen NA, de Hartog J, Harssema H, Knape M, van Vliet P. Air pollution from truck traffic and lung function in children living near motorways. *Epidemiology* 1997;8:298–303.
2. Gauderman WJ, Avol E, Lurmann F, Kuenzli N, Gilliland F, Peters J, McConnell R. Childhood asthma and exposure to traffic and nitrogen dioxide. *Epidemiology* 2005;16:737–743.
3. Gordian ME, Haneuse S, Wakefield J. An investigation of the association between traffic exposure and the diagnosis of asthma in children. *J Expo Sci Environ Epidemiol* 2006;16:49–55.
4. McConnell R, Berhane K, Yao L, Jerrett M, Lurmann F, Gilliland F, Künzli N, Gauderman J, Avol E, Thomas D, *et al*. Traffic, susceptibility, and childhood asthma. *Environ Health Perspect* 2006;114:766–772.
5. van Vliet P, Knape M, de Hartog J, Janssen N, Harssema H, Brunekreef B. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways. *Environ Res* 1997;74:122–132.
6. Brauer M, Hoek G, Smit HA, de Jongste JC, Gerritsen J, Postma DS, Kerkhof M, Brunekreef B. Air pollution and development of asthma, allergy and infections in a birth cohort. *Eur Respir J* 2007;29:879–888.
7. English P, Neutra R, Scalf R, Sullivan M, Waller L, Zhu L. Examining associations between childhood asthma and traffic flow using a geographic information system. *Environ Health Perspect* 1999;107:761–767.
8. Janssen NAH, Brunekreef B, van Vliet P, Aarts F, Meliefste K, Harssema H, Fischer P. The relationship between air pollution from heavy traffic and allergic sensitization, bronchial hyperresponsiveness, and respiratory symptoms in Dutch schoolchildren. *Environ Health Perspect* 2003;111:1512–1518.
9. Morgenstern V, Zutavern A, Cyrys J, Brockow I, Gehring U, Koletzko S, Bauer CP, Reinhardt D, Wichmann HE, Heinrich J. Respiratory health and individual estimated exposure to traffic-related air pollutants in a cohort of young children. *Occup Environ Med* 2007;64:8–16.
10. Ryan PH, LeMasters G, Biagini J, Bernstein D, Grinshpun SA, Shukla R, Wilson K, Villareal M, Burkle J, Lockey J. Is it traffic type, volume, or distance? Wheezing in infants living near truck and bus traffic. *J Allergy Clin Immunol* 2005;116:279–284.
11. Weinmayr G, Romeo E, De Sario M, Weiland SK, Forastiere F. Short-term effects of PM_{10} and NO_2 on respiratory health among children with asthma or asthma-like symptoms: a systematic review and meta-analysis. *Environ Health Perspect* 2010;118:449–457.
12. Snyder TD, Dillow SA. Digest of education statistics 2010 [NCES 2011-015]. Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education; 2011.
13. Environmental and Human Health, Inc. Children's exposure to diesel exhaust on school buses. North Haven, CT: EHHI; 2002.
14. Behrentz E, Sabin LD, Winer AM, Fitz DR, Pankratz DV, Colome SD, Fruin SA. Relative importance of school bus-related microenvironments to children's pollutant exposure. *J Air Waste Manag Assoc* 2005;55:1418–1430.
15. Solomon GM, Campbell TR, Ruderman Feuer G, Masters J, Samkian A, Kavita AP. No breathing in the aisles: diesel exhaust inside school buses. New York: National Resources Defense Council and Coalition for Clean Air; 2001.
16. Adar SD, Davey M, Sullivan JR, Compher M, Szpiro A, Liu LJS. Predicting airborne particle levels aboard Washington State school buses. *Atmos Environ (1994)* 2008;42:7590–7599.
17. Hill LB, Zimmerman NJ, Gooch J. A multi-city investigation of the effectiveness of retrofit emissions controls in reducing exposures to particulate matter in school buses. Boston, MA: Clean Air Task Force; 2005.
18. Fitz DR, Winer AM, Colome SD, Behrentz E, Sabin LD, Lee SJ. Characterizing the range of children's pollutant exposure during school bus commutes: final report prepared for the California Air Resources Board. Sacramento, CA: California Air Resources Board; 2003.
19. Sabin LD, Behrentz E, Winer AM, Jeong S, Fitz DR, Pankratz DV, Colome SD, Fruin SA. Characterizing the range of children's air pollutant exposure during school bus commutes. *J Expo Anal Environ Epidemiol* 2005;15:377–387.
20. Wu CF, Delfino RJ, Floro JN, Quintana PJE, Samimi BS, Kleinman MT, Allen RW, Liu LJS. Exposure assessment and modeling of particulate matter for asthmatic children using personal nephelometers. *Atmos Environ* 2005;39:3457–3469.
21. Sabin LD, Kozawa K, Behrentz E, Winer AM, Fitz DR, Pankratz DV, Colome SD, Fruin SA. Analysis of real-time variables affecting children's exposure to diesel-related pollutants during school bus commutes in Los Angeles. *Atmos Environ* 2005;39:5243–5254.
22. Rea AW, Zufall MJ, Williams RW, Sheldon L, Howard-Reed C. The influence of human activity patterns on personal PM exposure: a comparative analysis of filter-based and continuous particle measurements. *J Air Waste Manag Assoc* 2001;51:1271–1279.
23. Neeft JPA, Makkee M, Moulijn JA. Diesel particulate emission control. *Fuel Process Technol* 1996;47:1–69.
24. Hammond D, Jones S, Lalor M. In-vehicle measurement of ultrafine particles on compressed natural gas, conventional diesel, and oxidation-catalyst diesel heavy-duty transit buses. *Environ Monit Assess* 2007;125:239–246.
25. Trenbath K, Hannigan MP, Milford JB. Evaluation of retrofit crankcase ventilation controls and diesel oxidation catalysts for reducing air pollution in school buses. *Atmos Environ* 2009;43:5916–5922.
26. Westphal GA, Krahl J, Munack A, Ruschel Y, Schröder O, Hallier E, Brüning T, Bünger J. Mutagenicity of diesel engine exhaust is eliminated in the gas phase by an oxidation catalyst but only slightly reduced in the particle phase. *Environ Sci Technol* 2012;46:6417–6424.
27. Rim D, Siegel J, Spinhirne J, Webb A, McDonald-Buller E. Characteristics of cabin air quality in school buses in central Texas. *Atmos Environ* 2008;42:6453–6464.

28. Zhang Q, Zhu Y. Performance of school bus retrofit systems: ultrafine particles and other vehicular pollutants. *Environ Sci Technol* 2011; 45:6475–6482.
29. Stanislaus A, Marafi A, Rana MS. Recent advances in the science and technology of ultra low sulfur diesel (ULSD) production. *Catal Today* 2010;153:1–68.
30. U.S. Environmental Protection Agency (EPA). Report to Congress: highlights of the diesel emissions reduction program. Washington DC: EPA; 2009.
31. Adar SD, Hallstrand TS, Kaufman JD, Liu LS. Changes in pulmonary function in childhood are associated with exposures to traffic from school bus exhaust and residential proximity to roadways [abstract]. *Am J Respir Crit Care Med* 2009;179:A4737.
32. Sally Liu LJ. Modeling children's exposures to diesel exhaust from commuting by diesel school buses before and after engine [abstract]. *Epidemiology* 2006;17:S36.
33. Liu L, Adar SD, Hallstrand T. Respiratory effects of exposures to diesel exhaust among children bus riders before and after the diesel bus engine retrofit [abstract]. *Epidemiology* 2008;19:S300.
34. Sacks JD, Stanek LW, Luben TJ, Johns DO, Buckley BJ, Brown JS, Ross M. Particulate matter-induced health effects: who is susceptible? *Environ Health Perspect* 2011;119:446–454.
35. Liu LJS, Phuleria HC, Webber W, Davey M, Lawson DR, Ireson RG, Zielinska B, Ondov JM, Weaver CS, Lapin CA, *et al*. Quantification of self pollution from two diesel school buses using three independent methods. *Atmos Environ (1994)* 2010;44:3422–3431.
36. American Thoracic Society; European Respiratory Society. ATS/ERS recommendations for standardized procedures for the online and offline measurement of exhaled lower respiratory nitric oxide and nasal nitric oxide, 2005. *Am J Respir Crit Care Med* 2005;171: 912–930.
37. Jenkins MA, Clarke JR, Carlin JB, Robertson CF, Hopper JL, Dalton MF, Holst DP, Choi K, Giles GG. Validation of questionnaire and bronchial hyperresponsiveness against respiratory physician assessment in the diagnosis of asthma. *Int J Epidemiol* 1996;25: 609–616.
38. Wypij D, Pugh M, Ware JH. Modeling pulmonary function growth with regression splines. *Stat Sin* 1993;3:329–350.
39. Berhane K, Gauderman WJ, Stram DO, Thomas DC. Statistical issues in studies of the long-term effects of air pollution: the Southern California Children's Health Study. *Stat Sci* 2004;19:414–434.
40. Bloom B, Jones LI, Freeman G. Summary health statistics for U.S. children: National Health Interview Survey, 2012. *Vital Health Stat 10* 2013;258:1–81.
41. Peters SP, Ferguson G, Deniz Y, Reisner C. Uncontrolled asthma: a review of the prevalence, disease burden and options for treatment. *Respir Med* 2006;100:1139–1151.
42. Beatty TK, Shimshack JP. School buses, diesel emissions, and respiratory health. *J Health Econ* 2011;30:987–999.
43. Levy DE, Winickoff JP, Rigotti NA. School absenteeism among children living with smokers. *Pediatrics* 2011;128:650–656.
44. Ireson RG, Easter MD, Lakin ML, Ondov JM, Clark NN, Wright DB. Estimation of diesel particulate matter concentrations in a school bus using a fuel-based tracer—a sensitive and specific method for quantifying vehicle contributions. *Transport Res Record* 2004;1880: 21–28.
45. Larson T, Zielinska B, Ireson R, Liu LS. Source apportionment of $PM_{2.5}$ inside two school buses using partial least squares regression discriminant analysis with chemical mass balance. *Atmos Pollut Res* 2011;2:144–150.
46. Hesterberg TW, Long CM, Sax SN, Lapin CA, McClellan RO, Bunn WB, Valberg PA. Particulate matter in new technology diesel exhaust (NTDE) is quantitatively and qualitatively very different from that found in traditional diesel exhaust (TDE). *J Air Waste Manag Assoc* 2011;61:894–913.
47. Tang S, Frank BP, Lanni T, Rideout G, Meyer N, Beregszaszy C. Unregulated emissions from a heavy-duty diesel engine with various fuels and emission control systems. *Environ Sci Technol* 2007;41:5037–5043.
48. Laroo CA, Schenk CR, Sanchez LJ, McDonald J. Emissions of PCDD/ Fs, PCBs, and PAHs from a modern diesel engine equipped with catalyzed emission control systems. *Environ Sci Technol* 2011;45: 6420–6428.
49. Zhao H, Ge Y, Zhang T, Zhang J, Tan J, Zhang H. Unregulated emissions from diesel engine with particulate filter using Fe-based fuel borne catalyst. *J Environ Sci (China)* 2014;26:2027–2033.
50. Heeb NV, Schmid P, Kohler M, Gujer E, Zennegg M, Wenger D, Wichser A, Ulrich A, Gfeller U, Honegger P, *et al*. Impact of low- and high-oxidation diesel particulate filters on genotoxic exhaust constituents. *Environ Sci Technol* 2010;44:1078–1084.
51. Ibald-Mulli A, Wichmann H-E, Kreyling W, Peters A. Epidemiological evidence on health effects of ultrafine particles. *J Aerosol Med* 2002; 15:189–201.
52. Barnes PJ, Dweik RA, Gelb AF, Gibson PG, George SC, Grasemann H, Pavord ID, Ratjen F, Silkoff PE, Taylor DR, *et al*. Exhaled nitric oxide in pulmonary diseases: a comprehensive review. *Chest* 2010;138: 682–692.
53. Anderson PJ, Wilson JD, Hiller FC. Respiratory tract deposition of ultrafine particles in subjects with obstructive or restrictive lung disease. *Chest* 1990;97:1115–1120.
54. Lim HB, Ichinose T, Miyabara Y, Takano H, Kumagai Y, Shimojyo N, Devalia JL, Sagai M. Involvement of superoxide and nitric oxide on airway inflammation and hyperresponsiveness induced by diesel exhaust particles in mice. *Free Radic Biol Med* 1998;25:635–644.
55. Steerenberg PA, Nierkens S, Fischer PH, van Loveren H, Opperhuizen A, Vos JG, van Amsterdam JG. Traffic-related air pollution affects peak expiratory flow, exhaled nitric oxide, and inflammatory nasal markers. *Arch Environ Health* 2001;56:167–174.
56. van Amsterdam JG, Hollander A, Snelder JD, Fischer PH, van Loveren H, Vos JG, Opperhuizen A, Steerenberg PA. The effect of air pollution on exhaled nitric oxide of atopic and nonatopic subjects. *Nitric Oxide* 1999;3:492–495.
57. Steerenberg PA, Bischoff EW, de Klerk A, Verlaan AP, Jongbloets LM, van Loveren H, Opperhuizen A, Zomer G, Heisterkamp SH, Hady M, *et al*. Acute effect of air pollution on respiratory complaints, exhaled NO and biomarkers in nasal lavages of allergic children during the pollen season. *Int Arch Allergy Immunol* 2003;131:127–137.
58. Pourazar J, Mudway IS, Samet JM, Helleday R, Blomberg A, Wilson SJ, Frew AJ, Kelly FJ, Sandström T. Diesel exhaust activates redox-sensitive transcription factors and kinases in human airways. *Am J Physiol Lung Cell Mol Physiol* 2005;289:L724–L730.
59. Koenig JQ, Jansen K, Mar TF, Lumley T, Kaufman J, Trenga CA, Sullivan J, Liu LJ, Shapiro GG, Larson TV. Measurement of offline exhaled nitric oxide in a study of community exposure to air pollution. *Environ Health Perspect* 2003;111:1625–1629.
60. Fischer PH, Steerenberg PA, Snelder JD, van Loveren H, van Amsterdam JGC. Association between exhaled nitric oxide, ambient air pollution and respiratory health in school children. *Int Arch Occup Environ Health* 2002;75:348–353.
61. Rojas-Martinez R, Perez-Padilla R, Olaiz-Fernandez G, Mendoza-Alvarado L, Moreno-Macias H, Fortoul T, McDonnell W, Loomis D, Romieu I. Lung function growth in children with long-term exposure to air pollutants in Mexico City. *Am J Respir Crit Care Med* 2007;176:377–384.
62. Gauderman WJ, Avol E, Gilliland F, Vora H, Thomas D, Berhane K, McConnell R, Kuenzli N, Lurmann F, Rappaport E, *et al*. The effect of air pollution on lung development from 10 to 18 years of age. *N Engl J Med* 2004;351:1057–1067.
63. Evans KA, Halterman JS, Hopke PK, Fagnano M, Rich DQ. Increased ultrafine particles and carbon monoxide concentrations are associated with asthma exacerbation among urban children. *Environ Res* 2014;129:11–19.
64. Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, London SJ, Margolis HG, McConnell R, Islam KT, *et al*. The effects of ambient air pollution on school absenteeism due to respiratory illnesses. *Epidemiology* 2001;12:43–54.
65. Park H, Lee B, Ha EH, Lee JT, Kim H, Hong YC. Association of air pollution with school absenteeism due to illness. *Arch Pediatr Adolesc Med* 2002;156:1235–1239.
66. Avol EL, Gauderman WJ, Tan SM, London SJ, Peters JM. Respiratory effects of relocating to areas of differing air pollution levels. *Am J Respir Crit Care Med* 2001;164:2067–2072.
67. Wang X, Wypij D, Gold DR, Speizer FE, Ware JH, Ferris BG Jr, Dockery DW. A longitudinal study of the effects of parental smoking on pulmonary function in children 6-18 years. *Am J Respir Crit Care Med* 1994;149:1420–1425.