STATEMENT

Synopsis of Research Report 194

HEALTH EFFECTS INSTITUTE

A Dynamic Three-Dimensional Exposure Model for Hong Kong

INTRODUCTION

Exposure to traffic-related air pollution has been associated with various adverse health effects. However, exposure assessment is challenging because traffic-related air pollution is a complex mixture of many particulate and gaseous pollutants and is characterized by high spatial and temporal variability. A range of models, such as dispersion, land-use regression, and hybrid models, have been developed to estimate exposure to traffic-related air pollution, and these have been largely two-dimensional so far. Dr. Benjamin Barratt from King's College London and his team proposed to estimate exposure to traffic-related air pollution using a dynamic three-dimensional land-use regression (LUR) model for Hong Kong. Such a model would potentially have a wide application given that high-density, high-rise megacities have become more prominent globally. High-rise buildings, which can house hundreds or even a few thousand people, are therefore of great interest and have risen rapidly in most megacities; such buildings can also create urban street canyons, which are the focus of the current study.

APPROACH

The investigators conducted street-level outdoor monitoring campaigns to measure particulate matter ≤ 2.5 µm in aerodynamic diameter ($PM_{2.5}$), black carbon (BC), nitrogen monoxide (NO), and nitrogen dioxide (NO_2) concentrations at about 100 locations during two weeks in the warm season and two weeks in the cold season of 2014. The investigators then constructed exposure models of increasing complexity. First, the measurements were used to develop two-dimensional land-use regression models to estimate long-term exposure for Hong Kong. Among the many predictor variables considered in the models were *conventional* variables, such as traffic intensity, land-use variables, and distance to sources (e.g., ports or airports), as well as some more complex urban development predictors, such as aspect ratio (the ratio of building height to street width) to capture street canyons.

What This Study Adds

- High-density high-rise megacities have become more prominent globally. This is one of the first studies to integrate vertical gradients and time–activity patterns into an air pollution exposure model.
- Strong aspects of the study include the extensive air quality measurements, the development of exposure models using state-of-the-art approaches, and the application of those models to an existing Hong Kong elderly cohort for epidemiological analyses.
- Associations were fairly similar when comparing results from the complex models to the two-dimensional models for $PM_{2.5}$, BC, NO, and NO_2. Neither the incorporation of vertical gradients nor that of dynamic components, including indoor pollutant infiltration, into the exposure estimates resulted in meaningful or consistent changes in the associations with all-natural-cause, cardiovascular, and respiratory mortality in the cohort.
- Based on this and other work, it appears that the addition of a vertical gradient improves exposure model performance, although the added value may be modest, depending on pollutant and study area.

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Benjamin Barratt at King's College London, UK, and colleagues. The complete report, *A Dynamic Three-Dimensional Air Pollution Exposure Model for Hong Kong* (© 2018 Health Effects Institute), can be obtained from HEI or our website (see last page). **BARRATT 194**

Additionally, the investigators carried out vertical outdoor and indoor air pollution monitoring of $PM_{2.5}$ and BC at four heights at both sides of six streets — four canyon streets and two open streets. The mean sampling heights of the lowest sampling points across the streets was 10 meters above street level (1st residential floor). The maximum sampling height was 60 meters (21st residential floor). Subsequently, outdoor $PM_{2.5}$ and BC data were used to develop three-dimensional land-use regression models. Indoor sampling was included to assess infiltration rates, which were integrated into the dynamic land-use regression model described later.

Next, the investigators developed what they termed *dynamic* models to incorporate time–activity patterns into the land-use regression exposure models, using aggregated data from a large travel behavior survey of Hong Kong residents. This information was combined with results from previous monitoring studies in different modes of transport in Hong Kong to predict exposure in different transport microenvironments.

Finally, Barratt and colleagues applied the exposure models with increasing complexity in an epidemiological study using an existing elderly cohort of 66,000 Hong Kong residents to evaluate the potential impact of exposure measurement error in mortality estimates. The cohort was recruited in 1998–2001, and mortality data were collected until the end of 2011. The average residential height above street level was 39 meters (~11th floor). Exposure was estimated at the recruitment residential address using the 2014 exposure estimates, and back-extrapolated to the recruitment period using data from regulatory monitoring sites. The investigators ran standard Cox proportional hazard models that were adjusted for important individual-level confounder variables, such as age, sex, body mass index, physical activity, smoking, and socioeconomic status.

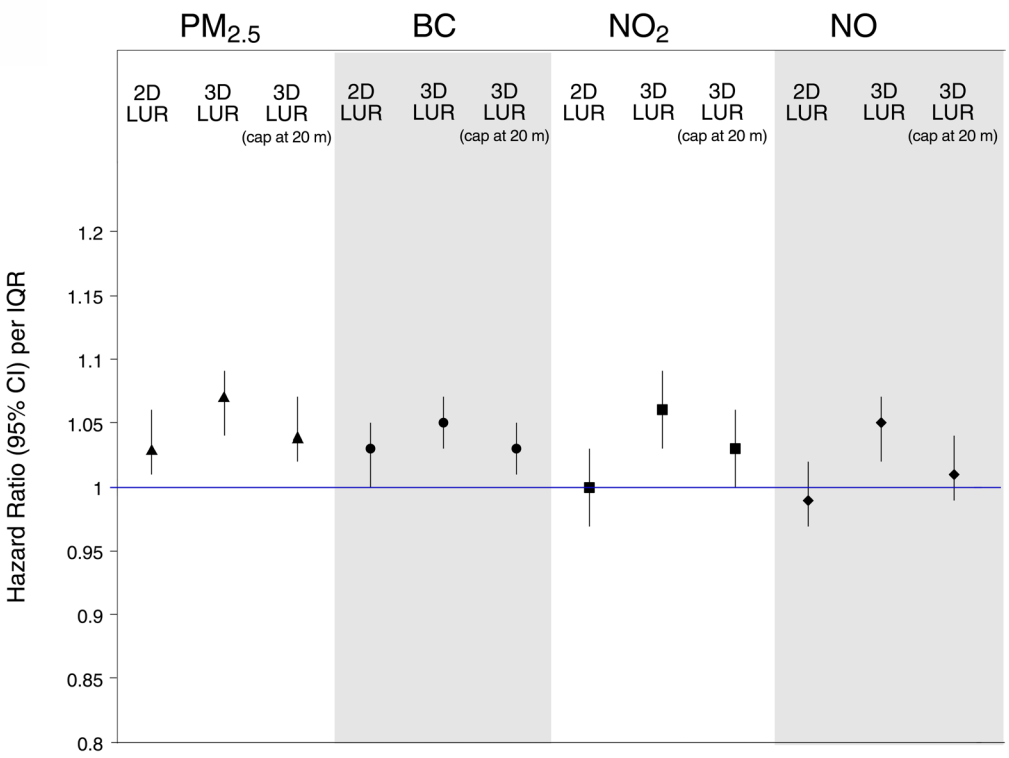
MAIN RESULTS AND INTERPRETATION

In its independent review of the study, the HEI Review Committee concluded that Barratt and colleagues conducted a novel study — one of the first to integrate vertical gradients and time–activity patterns into an air pollution exposure model. Strong aspects of the study include the extensive air quality measurements, the development of exposure models using state-of-the art approaches, and the application of those models to an existing Hong Kong elderly cohort for epidemiological analyses. The Committee concluded that Barratt and colleagues have found fairly similar associations when comparing results from the complex models to the two-dimensional models for $PM_{2.5}$, BC, NO, and NO_2. Neither the incorporation of vertical gradients nor that of dynamic components, including indoor pollutant infiltration, into the exposure estimates resulted in meaningful or consistent changes in the associations with all-natural-cause (see Statement Figure), cardiovascular, and respiratory mortality in the Hong Kong elderly cohort.

The Committee noted that the investigators encountered many challenges in the study and had developed approaches to compensate for those challenges in a variety of ways, but thought that the impacts of the various workarounds on the results had not been fully explored. For example, in the three-dimensional NO_2 and NO models, the investigators used the decay rate of BC to fill the gap in vertical measurements, but the impact was not further explored. Additionally, the Committee thought that the prediction accuracy of the two-dimensional LUR models was rather modest, which may suggest that alternative modeling strategies and decisions may be necessary for further improvements.

The investigators' further exploration of the vertical gradient component of the model at the Committee's request was revealing because it showed that results were sensitive to the choice of the model. Sensitivity analyses revealed the influence of substituting the modeled two-dimensional LUR estimates for missing measurements at lower floors and assuming that the air was well mixed at heights above 20 meters. The Committee thought more insights were gained from the vertical gradient model than from the dynamic component of the model because the latter was based on aggregated survey data, which makes interpretation difficult.

Based on the current study as well as findings from earlier studies, the addition of a vertical gradient — or more generally street configuration and building height to capture exposure on canyon streets — appears to improve exposure model performance, although the added value may be modest, depending on pollutant and study area. It should be realized that relationships between floor of residence in high-rise buildings and health are complex and highly contextual, and that floor of residence may also act as a confounding factor in air pollution health studies. Although appropriate steps were taken throughout the study to increase



Statement Figure. Association between air pollution and all-natural-cause mortality using different exposure models (two-dimensional versus three-dimensional models; dynamic model not shown).

generalizability of results, it remains unclear to what extent the vertical gradient model is applicable to the entire city of Hong Kong and to other Asian megacities with large populations living in high-rise buildings. Finally, the use of a vertical gradient component in exposure models for future epidemiological studies that make use of administrative databases is likely to be limited, partly because administrative data do not typically contain residential floor information.

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