HEI

STATEMENT

Synopsis of Research Report 170

HEALTH EFFECTS INSTITUTE

Impact of the 1990 Hong Kong Legislation for Restriction on Sulfur Content in Fuel

INTRODUCTION

On July 1, 1990, the government in Hong Kong implemented a new restriction on sulfur in fuel, mandating a limit of 0.5% sulfur by weight. After the full impact of this regulation was realized, airborne sulfur dioxide (SO_2) concentrations were reduced by 45% on average and by as much as 80% in some districts, although other components of the pollutant mixture, including particle mass, measured as particulate matter $\leq$ 10 μm in aerodynamic diameter (PM_{10}), did not decline. The reductions in the SO_2 concentrations were estimated in previous studies to have resulted in health improvements, including decreases in mortality rates and improvements in life expectancy.

The current study by Dr. Chit-Ming Wong of The University of Hong Kong and colleagues aimed to extend this earlier work in two ways: First, the investigators proposed to explore the role that specific chemical constituents of particulate air pollution may have played in the effects on mortality of the 1990 Hong Kong restriction of sulfur in fuels, hereafter referred to as "the intervention." They also proposed to develop methods for estimating the impact on life expectancy of an improvement in air quality after the imposition over a brief interval of a change in fuel quality, and to apply these methods in the context of the intervention. These objectives entailed evaluating the effects on mortality due to short-term changes in air quality after the intervention (specifically changes in levels of particle and gaseous pollutants and in particular chemical components or "species" of particulate air pollution); developing new and improved methods for assessing the health impact, in terms of the change in life expectancy, resulting from interventions taken to improve air quality; and determining whether or not improvements in air quality had any relation to short-term and long-term health benefits.

APPROACH

The investigators obtained counts of daily deaths from specific causes for the Hong Kong population between January 1, 1985, and June 30, 1995, a period that extends from 5 years before to 5 years after the imposition of the sulfur reduction. They also obtained measured ambient concentrations of air pollutants from the Hong Kong Environmental Protection Department from a network of 13 stations that operated in Hong Kong over the 10-year period of the study. Daily average concentrations of the gaseous pollutants nitrogen dioxide (NO_2), SO_2, and ozone (O_3) were derived from hourly measurements. Data on PM_{10} and associated chemical species were measured on every third and sixth day, respectively. Concentrations of specific chemical species were estimated by chemical analysis of the PM_{10} collected in filters using the gravimetric method. The investigators obtained daily mean temperature (°C) and relative humidity (%) data from the Hong Kong Observatory.

The investigators compared mean levels of pollutants between pre- and post-intervention periods using standard statistical methods (*t* tests and analysis of variance) to assess mean differences in concentrations. The investigators used Poisson regression methods to estimate the effects of short-term exposure to air pollution on daily mortality rates for all natural causes and for cardiovascular and respiratory causes, at all ages and in the 65-years-or-older age group, taking into account long-term trends and seasonal variation in daily mortality rates and variation in temperature and relative humidity. They also compared alternative models using both statistical tests and visual inspection of results.

The regression models were used to estimate the effects of gaseous pollutants, PM_{10}, and various

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associated chemical species on daily mortality rates for the periods 5 years before and 5 years after the intervention, as well as in the 10-year period pre- and post-intervention. They also conducted sensitivity analyses in which the pre-intervention time periods were shortened and ran analyses in which indicator variables were used to represent the intervention. All effects were reported as excess risks (ERs), defined as the percentage change in mortality per 10-$\mu g/m^3$ and 10-ng/m^3 increase in the concentrations of the four criteria pollutants and PM-associated chemical species, respectively. ERs were estimated for exposure cumulated over the day of death and the preceding day and for exposure to chemical species on the day of death.

The investigators developed two methods to estimate the effect of the intervention on life expectancy, which differ with regard to the outcome variable. In the first method, they used the daily age-standardized mortality rate, and in the second, the daily mortality count. Both methods were used to evaluate the relation between outcome variables and daily air pollution concentrations in the current day back to all previous days in the past 3 to 4 years.

RESULTS

The investigators included 275,254 deaths between 1985 and 1995 in the study, after excluding records that did not meet quality control specifications. They reported that the average daily number of deaths from all natural causes for all ages was 69 in the 5-year pre-intervention period and 76 in the 5-year post-intervention period. Cardiovascular and respiratory mortality comprised approximately 30% and 18% of total mortality, respectively, in both periods.

The investigators reported decreases in NO_2 and SO_2 concentrations between pre-intervention and post-intervention periods, which were particularly pronounced in the more heavily polluted industrial areas, but no consistent changes in PM_{10} concentrations after the intervention. The investigators reported decreases in each of seven PM_{10}-associated chemical species: aluminum, iron, manganese, nickel, vanadium, lead, and zinc between pre- and post-intervention periods. Of these, the reductions in nickel and vanadium were the most consistent and statistically significant.

The investigators analyzed the relation between short-term exposure to air pollution and daily mortality using data for the entire 10-year period from 1985 to 1995, and reported increased ERs for mortality due to all natural causes for both SO_2 and NO_2, and for mortality from cardiovascular causes for SO_2 and respiratory causes for NO_2. O_3 was also associated with an increase in deaths due to all natural causes and respiratory disease. Neither PM_{10} nor most PM_{10}-associated chemical species were consistently or statistically associated with increased ER. However, the investigators reported that both nickel and vanadium were associated with an increased ER from respiratory causes, especially in those older than 65 years.

The investigators reported that only NO_2 was associated with increased daily mortality in the pre-intervention period. This association was particularly pronounced for respiratory causes of death in those older than 65 years. Post-intervention, they reported that the various gaseous pollutants were associated with an increased ER of mortality from all natural causes and from cardiovascular and respiratory diseases. However, the investigators reported no statistically significant associations between PM_{10} and mortality in either the pre- or post-intervention periods, and little evidence of an association in the pre-intervention period between mortality and exposure to most of the chemical species. Nickel and vanadium, however, were associated with mortality from both all natural causes and respiratory disease, especially in those older than 65 years. In the post-intervention period, the investigators reported that most ERs for the individual chemical species were lower than in the pre-intervention period, though the ER of nickel for mortality due to all natural causes was higher in the 5-year pre-intervention period for both age groups.

The investigators reported that most gaseous pollutants were associated with increases in the ER of mortality after the intervention. The most pronounced increases were associated with NO_2 and SO_2 on cardiovascular mortality and for NO_2 and O_3 on respiratory mortality. They also observed that neither PM_{10} nor most chemical species were consistently associated with changes in ER, although zinc and manganese showed some evidence of associations with cardiovascular mortality. However, both nickel and vanadium were associated with a decline in ER of mortality, a finding that was replicated in a sensitivity analyses.

The investigators reported estimates of effects on life expectancy due to air pollution exposure over a 21-year period from 1985 through 2005. They stated that although some analyses suggested a relatively rapid but unsustained increase in life expectancy associated with the intervention, they were unable to reliably estimate the effect of the intervention on life expectancy using approaches based on either the daily age-standardized mortality rate or the daily mortality count, because they could not adequately adjust for the effects of season on mortality or for the effects of long-term trends in mortality rates that had occurred in the population of Hong Kong.

INTERPRETATION AND CONCLUSIONS

The reduction in the sulfur content of fuel in Hong Kong, implemented over a relatively brief period in 1990, and the health effects associated with it have been the subject of several epidemiologic studies. The current study by Wong and colleagues explored the effects of the reduction in the sulfur content of fuel on mortality in more detail, taking advantage of the marked step change in a major source of air pollution, an extended 10-year period of observation of both air pollution and mortality in Hong Kong, and additional, detailed measurements of specific chemical constituents of PM_{10} and gaseous pollutants. The extended period of observation also afforded Wong and colleagues the opportunity to develop and apply innovative methods to estimate the effects of reduction in the sulfur content of fuel on life expectancy using daily mortality rates, a controversial approach with potential applications to similar interventions. Dr. Wong's team was particularly well suited to carry out this ambitious research agenda, building on their extensive prior work on air quality and health in Hong Kong. However, they met with, at best, limited success.

The investigators applied conventional analytic methods for the analysis of daily time-series data and reported associations over a 10-year period from 1985 to 1995. They reported estimates for the effects of the gaseous pollutants and PM_{10} that are broadly consistent, both in direction and magnitude if not statistical precision, with many previous studies. The analyses of PM-associated chemical species indicated particularly strong associations between mortality and exposure to the specific chemical components nickel and vanadium, constituents derived mainly from the combustion of bunker fuels with high sulfur content used in marine shipping. However, the current study has several important weaknesses that limit its contribution to knowledge about the effects of this much-studied intervention.

Although the investigators observed reductions in PM-associated nickel and vanadium concentrations associated with the intervention and reported adverse effects of short-term exposure to both of these components, they were unable to reliably link changes in their concentrations associated with the intervention to changes in the effects of short-term exposure in the pre- and post-intervention periods. The investigators acknowledge this and attribute their inability to demonstrate any effects of the intervention per se to the fact that nickel and vanadium concentrations were measured only on every sixth day. But other weaknesses may also be responsible.

The comparison of estimated pollution effects between models (in particular between pre- and post-intervention models) was complicated by different specifications of model components for time trends and temperature, and it is not clear how sensitive the results were to these alternative specifications. Moreover, the monitoring data reveal considerable spatial variation in concentrations of the various pollutants across Hong Kong and also considerable spatial differences in the temporal variation of air pollution levels among them. These uncertainties suggest that only tentative conclusions can be drawn from these time-series analyses.

In addition, the investigators were unable to disentangle the effects of individual pollutants, both gases and components in the particle fraction, on mortality over the 10-year period of the study. After adjustment for levels of nickel and vanadium, the associations with SO_2, which had provided the strongest evidence for an effect of the intervention, became statistically unstable. These analyses make clear that the effects of SO_2, nickel, and vanadium could not be separated in the current study and likely cannot be separated using the current set of data and analytic methods given the correlations among these pollutants. Perhaps this is not surprising given the common combustion sources of these pollutants (e.g., sulfur-rich bunker fuel used in marine shipping). The investigators conclude that they "cannot exclude the possibility that decreases in their concentrations were responsible for some of the observed health benefits due to the intervention." However, based on these results, it is not possible to confidently attribute such beneficial effects on mortality as may have occurred due to the intervention to any specific component of the air pollution mixture.

Wong and colleagues did conduct the first rigorous effort to estimate from daily time-series data the effects of long-term exposure on life expectancy. The theoretical basis for such estimates had been explored previously and appeared to offer some promise, and the long-term time-series data associated with the Hong Kong intervention seemed to present an ideal opportunity for practical application. Unfortunately, because of the inability to control for the effects of potential confounding factors correlated over the long term with air pollution, the results appear to offer little hope for estimating the effects on life expectancy from daily time-series data for use in scientific or policy applications.

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INVESTIGATORS' REPORT *by Wong et al.*

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