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Review article

A systematic review of cardiovascular emergency department visits, hospital admissions and mortality associated with ambient black carbon

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ABSTRACT

Background: Black carbon (BC) is a ubiquitous component of particulate matter (PM) emitted from combustion-related sources and is associated with a number of health outcomes.
Objectives: We conducted a systematic review to evaluate the potential for cardiovascular morbidity and mortality following exposure to ambient BC, or the related component elemental carbon (EC), in the context of what is already known about the associations between exposure to fine particulate matter ($PM_{2.5}$) and cardiovascular health outcomes.
Data sources: We conducted a stepwise systematic literature search of the PubMed database and employed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for reporting our results.
Study eligibility criteria: Studies meeting inclusion criteria (i.e., include a quantitative measurement of BC or EC used to characterize exposure and an effect estimate of the association of the exposure metric with ED visits, hospital admissions, or mortality due to cardiovascular disease) were evaluated for risk of bias in study design and results.
Study appraisal and synthesis methods: Risk of bias evaluations assess some aspects of internal validity of study findings based on study design, conduct, and reporting and identify potential issues related to confounding or other biases.
Results: The results of our systematic review demonstrate similar results for BC or EC and $PM_{2.5}$; that is, a generally modest, positive association of each pollutant measurement with cardiovascular emergency department visits, hospital admissions, and mortality. There is no clear evidence that health risks are greater for either BC or EC when compared to one another, or when either is compared to $PM_{2.5}$.
Limitations: We were unable to adequately evaluate the role of copollutant confounding or differential spatial heterogeneity for BC or EC compared to $PM_{2.5}$.
Conclusions and Implications of Key Findings: Overall, the evidence at present indicates that BC or EC is consistently associated with cardiovascular morbidity and mortality but is not sufficient to conclude that BC or EC is independently associated with these effects rather than being an indicator for $PM_{2.5}$ mass.
Systematic review registration number: Not available.

1. Introduction

Black Carbon (BC) is a component of fine particulate matter ($PM_{2.5}$) routinely measured in the U.S. and is generally present in submicron particles emitted from combustion-related sources including biomass burning, residential heating and cooking, industry, and transportation (U.S. EPA, 2009). There is strong evidence linking exposure to $PM_{2.5}$ to an array of health effects, including premature mortality. There remain regional differences in $PM_{2.5}$-related health effects reported in a number of epidemiologic studies that cannot be fully explained by

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geographical variations in ambient concentrations of $PM_{2.5}$ (U.S. EPA, 2009). It has been hypothesized that a component or subset of more toxicologically active components of $PM_{2.5}$ are influencing this variability, with a number of studies emphasizing a potential role of BC (Bell et al., 2007; Janssen et al., 2011).

There is a growing body of epidemiologic studies examining associations between BC and a number of adverse health outcomes, with early studies being summarized in reports by the U.S. EPA (2009, 2012) and the WHO (2012). In the last review of health evidence related to exposures to PM, completed in 2009, the U.S. EPA concluded that there was limited evidence that the chemical composition of PM would be a better surrogate to predict health effects related to PM than particle mass alone (U.S. EPA, 2009). The same conclusion was reached specifically for BC in a Report to Congress (U.S. EPA, 2012) that indicated the evidence for health effects associated with exposures to BC as a component of $PM_{2.5}$ and $PM_{2.5}$ as a whole were similar and that it would be difficult to identify effects solely attributable to BC. Other reviews using a source apportionment approach have found that exposures to source categories including BC are consistently associated with cardiovascular effects, but conclusions from these studies are limited to exposures to the source mixture and not BC alone (Stanek et al., 2011; Lippmann et al., 2013).

The WHO report (WHO, 2012) utilized an alternative approach, placing equal weight on risk estimates using both IQR and incremental increases in exposure. When incremental increases are used to estimate risk, and the same increment is used for both BC and $PM_{2.5}$, pollutants with ambient concentrations that often differ by an order of magnitude or more, it becomes more difficult to compare the results for BC to the results for $PM_{2.5}$ and to compare the results for BC across studies. This approach resulted in a different interpretation of the evidence and the conclusion that the associations between BC and health effects observed in epidemiologic studies were more robust than those observed for $PM_{2.5}$. This conclusion is based mainly on the fact that in copollutant models including measures of both BC and $PM_{2.5}$ mass, the effect estimates for BC were relatively unchanged, whereas the effect estimates for $PM_{2.5}$ were attenuated. This led to WHO's conclusion that “BC is a better indicator of harmful particulate substance from combustion sources (especially traffic) than undifferentiated PM mass” (WHO, 2012). Building on this conclusion that BC particles may pose a greater risk to health than other PM components, a recent study conducted a health impact assessment to estimate the public health burden of BC (Li et al., 2016).

Given the amount of evidence that has continued to accumulate since these reports and reviews were published, an updated evaluation is necessary. In particular, we have decided to focus on cardiovascular health effects as this is where the strongest evidence lies for the health effects of $PM_{2.5}$ and BC. This includes evidence for a variety of endpoints that contribute to our knowledge on potential mechanisms and exposure pathways, such as associations with oxidative stress, inflammation and biomarkers of cardiac disease (e.g., fibrinogen, von Willebrand factor), as well as other sub-clinical markers of cardiac disease (e.g., heart rate variability, arrhythmia). In this systematic review, we evaluate studies of severe cardiac effects, emergency department (ED) visits and hospital admissions due to cardiovascular morbidity, as well as mortality attributed to cardiovascular disease among humans following short- or long-term exposure to ambient BC or EC, in order to assess associations in the context of what is already known about the relationship between $PM_{2.5}$ and cardiovascular health outcomes. Specifically, we examine whether or not there is clear evidence for an independent effect of BC, separate from that attributed to $PM_{2.5}$, on these health outcomes. We evaluate the differences between the risk for these outcomes following exposure to BC and PM mass, with an interest in the trends and strength of the relationships from studies we identified that were conducted in North America, Europe and Asia.

This systematic review uses the following Population, Exposure, Comparison, Outcome, Study Design (PECOS) statement: In any population of adults (ages 18 +), including subgroups of susceptible individuals (P), what is the increase in risk of an emergency department visit, hospital admission or mortality related to a cardiovascular endpoint (O) per unit increase equal to the interquartile range (C) in $\mu g/m^3$ of short-term or long-term ambient concentrations of BC or EC (E), observed in time-series and case-crossover studies (for short-term exposure) and cohort studies (for long-term exposure) (S)?

2. Methods

2.1. Definition of black carbon and elemental carbon

BC is carbonaceous material defined by light absorbing capacity. Elemental carbon (EC) is another component of particulate matter routinely measured in the U.S. and is strongly correlated with BC, although they are not identical and have fundamentally different operational definitions (Arnott et al., 2005). EC contains only carbon that is not bound to other elements, and is defined using thermo-optical techniques. There are several measurement techniques available to quantify concentrations of BC or BC analogs (e.g., EC). The most commonly used techniques can be classified into two groups (U.S. EPA, 2012). Filter-based optical methods measure light absorption which is proportional to the BC concentration and quantify it to a mass concentration. Thermal-optical methods measure the carbon fraction that resists removal through heating to a high temperature to quantify the EC concentration. BC and EC values from these measurement methods are highly correlated (U.S. EPA, 2012). Furthermore, published studies show that the BC:EC ratios derived by commercial instrumentation are generally within 30% (U.S. EPA, 2012). BC and EC are both indicators for carbon-rich combustion sources, and are often used interchangeably in the literature. Therefore, both were evaluated in this review. The terms “soot” and “black smoke” have also been used to describe BC, however, because the definitions of soot and black smoke can vary and are often imprecise, we did not include studies of soot or black smoke in this review.

2.2. Search strategy

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used for our stepwise systematic literature search (Moher et al., 2009) (Fig. 1). The PubMed database was used to search for relevant BC or EC references (see Fig. 1 for search string) and the original search was conducted through September 30, 2015. An updated literature search using the same search strategy was conducted for the dates September 30, 2015 through June 15, 2017. Next, publications on cardiovascular health effects were identified in PubMed (search string also shown in Fig. 1), and the overlapping records between the two searches were selected for consideration. Study inclusion criteria were then applied. Inclusion criteria were:

- Each study be an original, peer-reviewed research article
- Each study be published in English
- Each study include a quantitative measurement of BC or EC and $PM_{2.5}$ used to characterize exposure
- Each study include an effect estimate of the association of the exposure metric with ED visits, hospital admissions, or mortality due to cardiovascular disease.

The references were first screened by a single author (JLN) by title and abstract for potential relevance. The full text of each screened reference was reviewed by one author (either TJL or JDS) to identify characteristics of the study design and health effects reported to determine if the study would inform this review. Studies that did not report a main effect for BC or EC but did evaluate the ability of BC or EC to modify the effect of $PM_{2.5}$ on a health effect were not included in the systematic review, but are characterized in the Discussion section.