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Original Article

Association between residence near surface coal mining and blood inflammation

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ABSTRACT

Previous research has documented that persons living near surface coal mining activity are at risk for poor health outcomes. The current study measured blood inflammation among adults ($N = 51$) living close to surface coal mining sites versus persons living farther away in Indiana and West Virginia, USA. None of the participants were smokers or coal miners, and none reported current acute illness. Participants completed a health interview and were tested for high sensitivity C-reactive protein as a measure of inflammation. We also collected indoor and outdoor particle counts and mass estimates at each residence. Results showed that mean C-reactive protein levels were significantly higher for residents who lived near mining, controlling for other risks (adjusted mean = 4.9 mg/L in the mining group and 0.9 mg/L in the non-mining group, $p < .03$). Mining residents also reported significantly more cardiopulmonary disease conditions and more illness symptoms. Particle counts were higher in the indoor and outdoor mining locations, and were most disparate for outdoor counts of particles in a respirable range between 0.5 μm and 5.0 μm. The results provide the first evidence that persons who live close to active surface coal mining show significantly elevated blood inflammation. Implications of results are discussed.

1. Introduction: proximity to surface coal mining and blood inflammation

Previous research has documented that persons living near coal mining sites have poor self-reported health outcomes and elevated population mortality rates (Hendryx, 2009; Hendryx and Ahern, 2009; Hendryx and Zullig, 2009). Limited evidence also documents poor environmental conditions in coal mining communities relative to control sites, including higher levels of particulate matter and relatively high presence of mining related constituents such as crystalline silica (Knuckles et al., 2013; Kurth et al., 2014b). Elevations in particulate matter from mining operations may be a contributing factor to poor population health in mining communities. However, no study to date has reported on direct biological markers of illness among people living in coal mining communities.

C-reactive protein (CRP) is an inflammatory marker produced in the liver in response to cytokine signaling (Black et al., 2004; Gabay and Kushner, 1999). High levels of CRP are predictive of an increased risk of cardiovascular disease (Ridker et al., 2000; Rutter et al., 2004) and poor lung function (Anderson, 2006; Folchini et al., 2011). High CRP may result from a variety of behavioral and environmental conditions. Smoking and obesity both increase risk for elevated CRP (Melbye et al., 2007). Environmental agents, notably particulate matter from traffic or industrial sources, has been found to be associated with elevated CRP on a chronic (Hoffmann et al., 2009) and acute (Chuang et al., 2007; Huttunen et al., 2012; Peters et al., 2001) basis, however, not all studies have observed this relationship (Rudez et al., 2009). Most studies of environmental conditions and inflammatory markers have been conducted in urban settings, and studies of associations for rural populations are relatively unexplored. Coal mining is predominately a rural-based activity and is known to increase localized ambient particulate matter (Ghose and Majee, 2007; Kolker et al., 2012; Kurth et al., 2014a,b).

The purpose of the current study was to test whether levels of C-reactive protein were significantly elevated in a rural sample living proximate to surface coal mining activity. Secondary goals were to gather additional evidence on levels of particulate matter and self-reported health for mining and non-mining community

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residents. To place the contribution of the study in perspective, we first offer a review of previous research on this topic.

2. Impacts of coal mining on public health: a review of the evidence

Despite a large body of evidence documenting occupational health problems for coal miners (Castranova and Vallyathan, 2000; Coggon and Taylor, 1998; Graber et al., 2014; Laney et al., 2012), until recently, little research had investigated possible public health consequences for persons living near coal mining activities. Among the earliest studies on this topic, Temple and Sykes (1992) showed increases in medical visits for asthma in conjunction with the opening of a surface mine in Great Britain. Also in Great Britain, Brabin et al. (1994) documented significantly higher respiratory symptoms among children exposed to coal dust, and a few years later, Pless-Mulloli and colleagues reported weak but significant associations between surface coal mining and children's respiratory health (Howel et al., 2001; Pless-Mulloli et al., 2000).

With the advent of large scale mountaintop removal (MTR) coal mining in the Appalachian US in the 1990s, anecdotal evidence (Burns, 2007; Goodell, 2006) began to emerge for its public health impacts, but empirical data were at first lacking. MTR is a particularly aggressive form of surface mining involving use of explosives and heavy machinery to remove hundreds of feet of rock and soil (i.e., overburden) above coal seams in steep terrain. The first study on the environmental public health impacts of US coal mining may be a study of hospitalization patterns associated with mining (Hendryx et al., 2007), followed shortly by an investigation of self-reported health indicators in association with higher levels of coal mining in Appalachian West Virginia (Hendryx and Ahern, 2008). A series of epidemiological studies emerged, some relying on ecological designs and/or secondary data (Ahern and Hendryx, 2012; Ahern et al., 2011a,b; Christian et al., 2011; Hendryx, 2009, 2011, 2013; Hendryx and Ahern, 2009; Hendryx and Innes-Wimsatt, 2013; Hendryx and Luo, 2014; Hendryx et al., 2008, 2012; Hendryx and Zullig, 2009; Zullig and Hendryx, 2010, 2011). All of these studies were limited to analysis of mortality statistics, morbidity self-reports, or secondary records of hospitalizations or birth certificate data. None included direct measures of environmental conditions in mining communities or direct measures of personal exposures. Nevertheless, the resulting pattern showed not only that a variety of health problems were significantly elevated in mining versus control communities after statistical control for other risks (e.g., age, sex, poverty, education, smoking, obesity, etc.) but also showed that health problems were proportional to tonnage of mining in a dose-response fashion, and that health problems were concentrated in MTR areas relative to areas where other forms of mining were practiced.

Meanwhile, a second research thread investigated the ecological impacts of coal mining on water quality (Lindberg et al., 2011; Palmer et al., 2010; Pond et al., 2008) and on air pollution (Ghose, 2007; Ghose and Banerjee, 1995; Pandey et al., 2014; Reynolds et al., 2003). Studies in this vein focused on assessments of environmental conditions rather than effects on humans and did not collect measurements specifically to assess conditions in human settlements. Regarding MTR specifically, important studies have documented serious and long term impairment to surface waters caused by MTR (Lindberg et al., 2011; Palmer et al., 2010; Pond et al., 2008). Air pollution specifically from MTR was not investigated.

Given the long history of coal mining, it is perhaps surprising that it took so long to examine what the environmental conditions in these communities actually were. A few studies have started to examine environmental conditions in residential mining communities and find evidence of elevated air and water pollution (Kurth et al., 2014a,b; Orem et al., 2012). Kurth et al. (2014a,b) have shown that MTR communities relative to controls have elevated levels of ultrafine material, and that elevated particulate matter in mining communities is predominantly a consequence of overburden removal from mining sites.

As these US studies were beginning to emerge, studies in other countries have also been published that show community health or environmental impacts from coal mining. These include a Turkish study of children's lead and cadmium exposure (Yapici et al., 2006), soil contamination in China (Liu et al., 2012; Wang et al., 2010), elevated rates of neural tube defects in China (Liao et al., 2010), impaired air quality in Columbia (Huertas et al., 2012), and environmental and health impacts in Australia (Higginbotham et al., 2010).

Most recently, going beyond mortality statistics or morbidity self-report, and beginning to merge environmental data with health data, particulate matter collected from ambient air sampling in MTR residential communities has been used in two laboratory studies. The first of these showed impaired microvascular function in rats upon respiratory exposure to MTR particulate matter (Knuckles et al., 2013). A second study found that particulate matter from MTR communities, but not from control communities, promoted tumor development and progression in human lung cells in vitro (Luanpitpong et al., 2014). Still, no US studies have collected data on biological health parameters for persons residing in communities near surface coal mining. The current study offers that new contribution.

3. Methods

3.1. Design and sample

We conducted a cross-sectional investigation of high sensitivity C-reactive protein (hsCRP) among adults living in rural communities within three miles of active surface coal mining compared to adults living farther away. Two surface coal mining areas in the eastern United States were included, one in Indiana and one in West Virginia; control participants were drawn from rural non-mining communities in the same states.

A total of 51 adults participated in the study. All samples were collected in August, 2014. Participants were recruited using a referral sampling approach beginning with initial contacts established by members of the research team. Participants then referred others who lived in mining and non-mining locations. All participants were non-smokers, not pregnant, and reported no current acute illness. No study participant used coal as a home heating source. Three adults who reported current employment as coal miners were excluded, resulting in a final sample of 48 including 23 in Indiana and 25 in West Virginia. There were 33 participants from households close to mining and 15 from non-mining control sites. Participants received modest financial incentives for participating in data collection activities. All participants underwent informed consent, and the study was reviewed and approved by the university Institutional Review Board.

Each individual was visited in their home where the blood sample was drawn, a health interview conducted, and air quality assessments made. The latitude and longitude of each household was recorded and the straight line distance was found between the residence and the boundary of the nearest active surface mining site. Wind speed and direction were recorded using data from the nearest weather monitoring station.

3.2. Measures

High sensitivity C-reactive protein (hsCRP) mg/L was measured using capillary finger sticks to collect dried blood spot samples. The