Linking Air Pollution and Health Effects

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With the help of David Herman, Rebecca Johnson, Lisa Wingen and a lot of other people

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Between 2013 and 2015, eight of the 10 cities in the US with the highest year-round concentration of PM2.5 were in California (ALA Report, 2018).
There is a Likely Causal Relationship Between Exposure to Particulate Air Pollution and Cardiovascular Disease (USEPA Integrated Health Assessment 2016).

- An increase in air pollutants leads to increased mortality and hospital admissions because of cardiovascular diseases (Analitis A. et al. 2006, Zanobetti et al. 2003, Dominici et al. 2006, Peel et al. 2007, Cesaroni et al., 2013).

- Relatively modest exposures to particulate matter in the ambient air are associated with increased morbidity and mortality associated with decreased heart rate variability, ST-segment depression, endothelial dysfunction, increased blood pressure and blood coagulability, and accelerated progression of atherosclerosis (Simkhovich et al. 2009).

- Exposure to elevated levels of particulate matter (PM) in ambient air leads to an increased heart rate (HR) and a decreased heart rate variability (HRV) in elderly patients (Dubowsky Adar S. et al. 2007, Luttmann-Gibson et al. 2006).

- Exposure to PM2.5 components and gaseous pollutants induce prolonged inflammatory and thrombotic reactions can cause autonomic nervous system imbalance (Chen et al. 2017).

- Reduced heart-rate variability is associated with increased risk of coronary events and with other cardiovascular disease risk factors, especially those that are more common in the insulin resistance syndrome, and is associated with increased coronary calcification in asymptomatic young adults (Colhoun et al., 2001).
PM2.5 is enriched with toxic organic and inorganic compounds.
Toxic Air Contaminants are produced by combustion

Figure 1. Combustor reaction zones. Zone 1, preflame, fuel zone; zone 2, high-temperature, flame zone; zone 3, postflame, thermal zone; zone 4, gas-quench, cool zone; zone 5, surface-catalysis, cool zone. PBDD/Fs, polybrominated dibenzo-\(p\)-dioxins and dibenzofurans. Reaction products from upstream zones pass through downstream zones and undergo chemical modifications, resulting in formation of new pollutants. Zone 2 controls formation of many “traditional” pollutants (e.g., carbon monoxide, sulfur oxides, and nitrogen oxides). Zones 3 and 4 control formation of gas-phase organic pollutants. Zone 5 is a major source of PCDD/Fs and is increasingly recognized as a source of other pollutants previously thought to originate in zones 1–4.
Most of the particles that seem to be the most biologically active are in the ultrafine particle (UFP) size range.
PM2.5 From Combustion Sources is a Mixture of Solid and Liquid Droplets that we call “SOOT”

- Black carbon (BC) is a major component of “soot”, a complex light-absorbing mixture that comprised of a mixture of Elemental Carbon (EC) and Particulate Organic Carbon (OC).
- BC is the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass.
- BC is emitted directly into the atmosphere in the form of fine particles (PM$_{2.5}$) and ultrafine particles (PM$_{0.1}$). These are also considered nanoparticles.
- BC is the most effective form of PM, by mass, at absorbing solar energy: per unit of mass in the atmosphere, BC can absorb a million times more energy than carbon dioxide (CO$_2$).
- Organic carbon aerosols are a significant absorber of solar radiation. The absorbing part of organic aerosols is referred to as "brown" carbon (BrC).

http://www.epa.gov/blackcarbon/basic.html
We designed a study to elucidate the mechanisms through which PM2.5 might induce toxicity and cardiovascular effects.
Health-related characteristics of Ultrafine PM

Organics
Sulfate
Ammonium
Nitrate

larger particles
oxygenated

ultrafines
less oxygenated
(to denuder)

\[
\begin{align*}
    \frac{m/z 44 \ (\text{CO}_2^+)}{m/z 55 \ (\text{C}_4\text{H}_7^+)} & \approx 0.4 \\
\end{align*}
\]

When you denude the UFP

\[
\begin{align*}
    \frac{m/z 44 \ (\text{CO}_2^+)}{m/z 55 \ (\text{C}_4\text{H}_7^+)} & \approx 4 \\
\end{align*}
\]

DTT activity, nmol/min/m³

Temperature, °C

HMW PAHs

Concentration, pg/m³

Temperature, °C

\[
\begin{align*}
    50 \text{ C} & : 14\% \\
    100 \text{ C} & : 53\% \\
    200 \text{ C} & : 81\% \\
\end{align*}
\]
Changes in O:C ratio correlate with changes in HRV. O₃ Oxidation May Alter Biological Activity
Increased concentrations of partially oxidized HCs (f43 ~ aldehydes and ketones) are associated with decreased HRV
Removing the Organic Constituents From Ambient UFP Blocks CV Effects

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>CAP</th>
<th>DeCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaque Size (% area of plaque in of total lumen CS)</td>
<td>14.5 ± 6.3</td>
<td>29.9 ± 10.0*</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td>Lipid Accumulation (% area of lipid in total tissue CS)</td>
<td>5.1 ± 3.3</td>
<td>8.9 ± 2.4,*</td>
<td>2.2 ± 0.3</td>
</tr>
<tr>
<td>Lipid Peroxidation (nM MDA/mg protein)</td>
<td>134 ± 29</td>
<td>218 ± 32*,**</td>
<td>141 ± 17</td>
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</tbody>
</table>

Aortic Arch 2x

Air

Denuded

Undenuded
ECG Waveform Changes Were Significant in Summer but not in Fall
Daily changes in ambient temperature are correlated with post-exposure changes in HF HRV in CAPs exposed mice.

Note: Temperature is AMBIENT temp for the particles in the atmosphere.

Temperature in the exposure chambers is held at 75 C, so mice were not subjected to different temperatures during exposures.
Conclusions

- Exposures to PM elicited significant changes in both heart rate-related and ischemia-related ECG parameters while exposures during cooler months had less effect;
- The predominance of unoxidized or partially oxidized (carbonyls) HC in PM was associated with worsened cardiac function.
- Oxidation, presumably of carbonyls to organic acids, reduced biological effects.
- On a day-to-day basis, exposures to PM on days with increased temperature were associated with a linear decrease in HRV.
- Climate warming will increase the number and severity of wildfires in California and can directly or indirectly increase the toxicity of ambient pollutants and worsen outcomes for individuals with pre-existing cardiopulmonary diseases.
Funding Sources

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Moving the AMS is a group effort!

Health studies are currently sponsored by the California Air Resources Board, the South Coast Air Quality Management District and the NIEHS.
Questions?