Linking Emission Sources, Atmospheric Processes and Health Effects of Atmospheric Organic Aerosols

Introduction

Increased pulmonary, cardiovascular diseases and premature mortalities have been attributed to ambient particulate matter (PM) due to the rapid urbanization and industrialization within the past few decades.[1] The elderly, women, children, people with pre-existing health conditions are especially vulnerable to the health effects of PM exposure.[2] Organic aerosols (OA), from primary and secondary sources, comprises a substantial fraction (20-90%) of $PM_{2.5}$ (i.e., particles that have a diameter $\leq$ 2.5 μm).[3] In the urban environments, primary OA (POA) are mainly emitted from combustion sources such as residential wood burning, vehicle emissions, and cooking activities.[3] For example, it has been estimated that the directly emitted $PM_{2.5}$ is 10.4 tons/day from cooking and 12.4 tons/per from vehicles in south coast of United States.[4] Secondary OA (SOA) are formed through the transformation of volatile organic compound (VOC) precursors in the presence of atmospheric oxidants.[3] The production of gasoline derived SOA can reach ~4 Tg per year.[5] Compared to POA, SOA has higher oxidation state and more diverse functionalities (e.g., carbonyls, quinones, hydroperoxides, nitrates, and carboxylic acids) that could significantly modify the health impact of $PM_{2.5}$.[3, 6] Among numerous OA constituents, quinones, which represent a class of highly reactive compounds found in POA, have been largely attributed to the observed OA-induced health effects, due to their high potency to induce oxidative stress in biological systems.[7] Recent studies have shown strong cellular inflammatory responses to biogenic SOA (e.g., isoprene SOA) that have no or low yields of quinones in composition.[8] **However, the roles of other OA components beyond quinones in modulating toxicological responses have not been fully understood. This research will bridge the gaps between observed health effects and chemical compositions of OA through the *in-vitro* toxicological studies as well as detailed chemical characterization using state-of-art instrumentations and chemical assays.**

Aims of Research

The proposed research will link OA compositions to observed toxicological responses in cultured human lung cells. The specific aims include:

Aim 1: Compare the chemical compositions and toxicity outcomes of OA from various sources, including the traffic-related aerosols, cooking aerosols and biogenic SOA.

Aim 2: Investigating the pathway of oxidative stress induced by OA.

Aim 3: Investigating the effects of atmospheric transformation on modifying the chemical compositions and toxicity of PM.

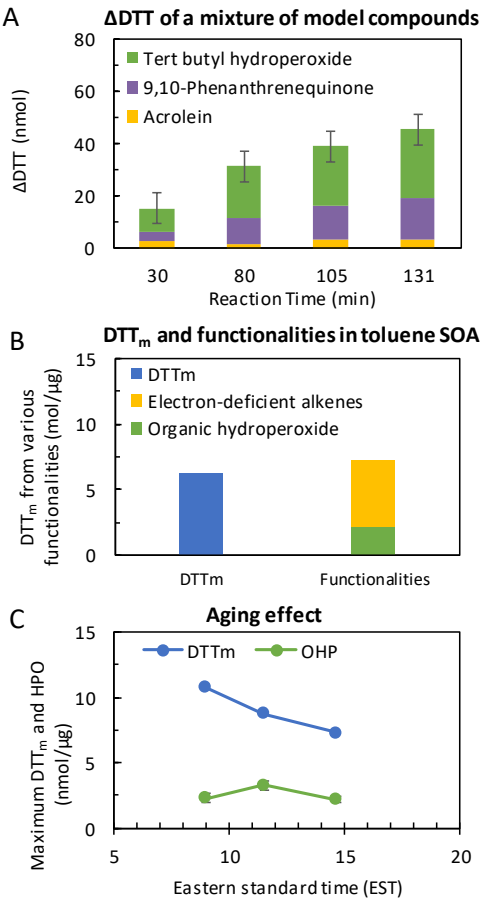
Methods and Expected Outcomes

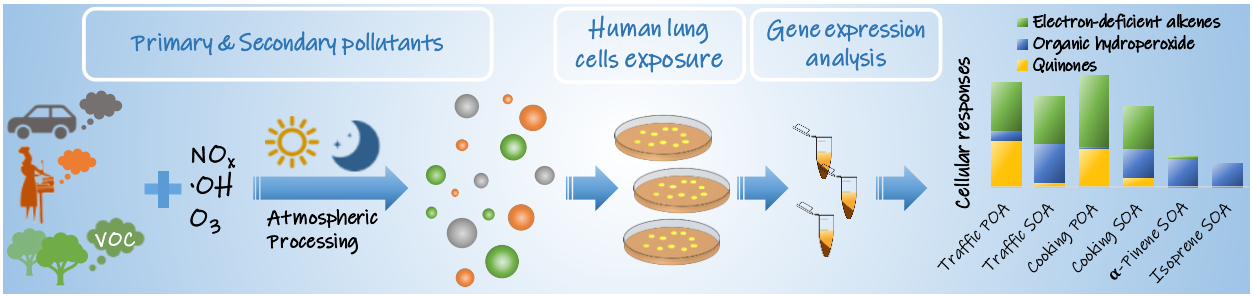
Emission experiments and molecular characterization of OA: Traffic-emitted PM will be collected using the Teflon filters from the vehicle emissions of a modern vehicle equipped with a gasoline direct injection engine. Cooking-emitted PM will be sampled during the cooking of meat using the charbroiler fired with natural gas in a full-scale cooking lab at University of California, Riverside (UCR) to simulate the emissions from commercial and residential kitchens. The primary emissions will be further injected into a 2 m^3 indoor Teflon chamber and irradiated with UV and Visible lights to simulate the atmospheric aging on PM compositions. SOA from biogenic VOC precursors (α-pinene and isoprene) will be generated in the world's largest indoor smog chamber (dual 90 m^3) in the Atmospheric Process Laboratory, UCR. Mass spectrometric techniques, including gas chromatography/mass spectrometry and ultraperformance liquid chromatography/electrospray ionization high-resolution quadrupole time-of-flight mass spectrometry will be applied to characterize the chemical compositions of OA. Dithiothreitol (DTT) assay, cysteine assay, and 2-mercaptoethanol assay will be applied to investigate the modification ability (oxidative potential) of PM on the thiol functional groups in biomolecues. 4-Nitroboronic acid assay and 2-4-dinitrophenylhydrazine assay will be utilized to quantify the concentration of organic hydroperoxides and carbonyls in OA, respectively.

Assessment of toxicological responses: Primary human lung cells from elderly or individuals with pre-existing cardiovascular or respiratory health conditions will be exposed to OA samples to assess toxicological responses. The dose-response relationship will be obtained for selected gene expressions. The correlation between oxidative potential or altered gene expression and chemical compositions will be analyzed using the principal component analysis. Then, the pathway-focused Human Oxidative Stress Plus RT^2 Profiler PCR array will be used to investigate the toxicity pathway of OA.

Preliminary data and expected outcomes: I have developed several chemical assays to measure OA chemical compositions and the modification ability of OA on biological thiols.[6] The assays can identify the main contributors (i.e., organic hydroperoxides, electron-deficient alkenes, and

quinones) to the oxidative potential of OA (Fig. A and B). Interestingly, with the progress of atmospheric transformation or aging process, the oxidative potential of OA was found to decrease in congruent with the decomposition of organic hydroperoxides (Fig. C). Based on these findings, I hypothesize that OA can induce significant oxidative stress in biological systems, especially for the elderly and individuals with pre-existing health conditions. The expected main contributors to the oxidative potential will vary in different OA systems, depending on the presence of specific functional groups. I will **build a predictive multiple linear regression model to estimate the contributions of OA functionalities to oxidative potential and the induced cellular responses** to bridge the gaps between the emission sources, atmospheric processes, chemical compositions and health outcomes. **The proposed framework is shown below.**



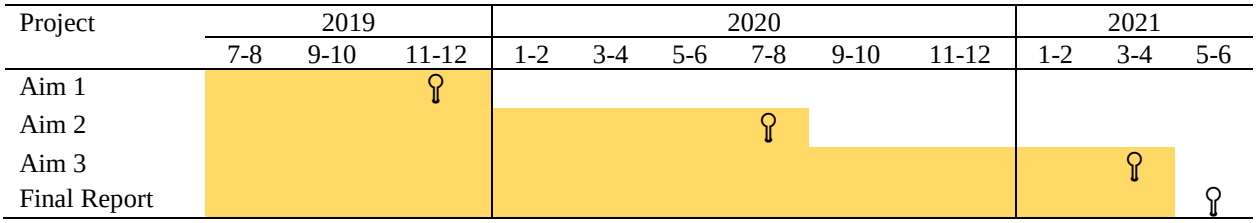


Implications

The proposed research will utilize *in-vitro* toxicological methods to investigate the biological responses to OA in vulnerable groups (i.e., the elderly and people with pre-existing health conditions), and apply state-of-art instrumentation combined with chemical assays to characterize the functionalities in OA. The toxicological studies on traffic-related PM can be linked to the health effects of PM on socioeconomically disadvantaged people who live near highway and suffer from high exposure to traffic-related PM. The oxidative potential and cellular

responses induced by cooking OA can have important implications for occupational health (e.g., workers in restaurants) and women. Results from this research will add our understanding to the evolution of OA under atmospheric transformations and provide new insights into the susceptibility of human beings to ambient PM. The ultimate goal of this research is to inform and protect public health, and reduce the health risks from PM exposure, especially for vulnerable and underrepresented groups.

Timeline



References

1. World Health Organization, Ambient (Outdoor) Air Quality and Health (fact sheet). 2016..

2. Ahmed, C.; Jiang, H.; Chen, J.; Lin, Y.-H., Traffic-Related Particulate Matter and Cardiometabolic Syndrome: A Review. *Atmosphere* **2018,** *9*, (9), 336.

3. Hallquist, M.; Wenger, J.; Baltensperger, U.; Rudich, Y.; Simpson, D.; Claeys, M.; Dommen, J.; Donahue, N.; George, C.; Goldstein, A., The formation, properties and impact of secondary organic aerosol: current and emerging issues. *Atmos. Chem. Phys.* **2009,** *9*, (14), 5155-5236.

4. South Coast Air Quality Management District Governing Board, PM controls 2016 AQMP White Paper, 2016.

5. Bahreini, R.; Middlebrook, A. M.; de Gouw, J. A.; Warneke, C.; Trainer, M.; Brock, C. A.; Stark, H.; Brown, S. S.; Dube, W. P.; Gilman, J. B.; Hall, K.; Holloway, J. S.; Kuster, W. C.; Perring, A. E.; Prevot, A. S. H.; Schwarz, J. P.; Spackman, J. R.; Szidat, S.; Wagner, N. L.; Weber, R. J.; Zotter, P.; Parrish, D. D., Gasoline emissions dominate over diesel in formation of secondary organic aerosol mass. *Geophysical Research Letters* **2012,** *39*, (6).

6. Jiang, H.; Jang, M., Dynamic Oxidative Potential of Atmospheric Organic Aerosol under Ambient Sunlight. *Environmental Science & Technology* **2018,** *52*, (13), 7496-7504.

7. Shiraiwa, M.; Ueda, K.; Pozzer, A.; Lammel, G.; Kampf, C. J.; Fushimi, A.; Enami, S.; Arangio, A. M.; Fröhlich-Nowoisky, J.; Fujitani, Y.; Furuyama, A.; Lakey, P. S. J.; Lelieveld, J.; Lucas, K.; Morino, Y.; Pöschl, U.; Takahama, S.; Takami, A.; Tong, H.; Weber, B.; Yoshino, A.; Sato, K., Aerosol Health Effects from Molecular to Global Scales. *Environmental Science & Technology* **2017,** *51*, (23), 13545-13567.

8. Lin, Y.-H.; Arashiro, M.; Martin, E.; Chen, Y.; Zhang, Z.; Sexton, K. G.; Gold, A.; Jaspers, I.; Fry, R. C.; Surratt, J. D., Isoprene-derived secondary organic aerosol induces the expression of oxidative stress response genes in human lung cells. *Environ. Sci. Technol. Lett.* **2016,** *3*, (6), 250-254.