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Thinking beyond $PM_{2.5}$: Ambient particulate matter size distributions influence particle deposition in the respiratory tract

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Human exposure to airborne particulate matter (PM) increases the risk of negative health outcomes; however, substantial uncertainty remains in quantifying these exposure-response relationships. In particular, relating increased risk of mortality to exposure to PM with diameters smaller than 2.5 μm ($PM_{2.5}$) neglects variability in the underlying size distribution of $PM_{2.5}$ exposure and size-resolved deposition in human airways. As particle deposition along the respiratory tract exhibits a strong size dependence, the fraction of PM mass that deposits is a function of ambient particle size distributions. In this study, we combine a size-resolved respiratory particle-deposition model with a global size-resolved aerosol microphysics model to estimate the variability in particle deposition along the respiratory tract due to variability in ambient PM size distributions. We find that the ratio of deposited PM mass in the respiratory system per unit ambient $PM_{2.5}$ exposure varies by 20-30% between highly populated regions (e.g., Eastern US vs. India) due to variability in ambient PM size distributions. Furthermore, this deposition ratio can vary by as high as a factor of 4 between the fossil-fuel-dominated region of the Eastern United States and the desert-dust-dominated region of North Africa. When considering individual PM species, such as sulfate or organic matter, we still find variability in size-resolved respiratory deposition on the order of 30% due to regional variability in the aerosol size distribution. Hence, even if the toxicity of PM can be attributed to specific species, one still may need to consider variability in the ambient size distribution. Finally, the spatial distribution of respiratory deposition rates based on particle number or surface area is substantially different than deposition based on particle mass. These results suggest that regional variability in ambient aerosol size distributions drive variability in PM deposition in the body, which may lead to variability in the health response from exposure to $PM_{2.5}$.