Ozone Uptake in the Nasal Passages of the Infant Rhesus Monkey: Predicting Lesion Location with Computational Fluid Dynamics

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Ozone, a common component of photochemical smog, is known to have harmful effects on the respiratory system. Infant rhesus monkeys exposed under controlled laboratory conditions to 0.5 parts per million (ppm) ozone develop lesions mainly in the anterior portion of the nasal passages. The intranasal location of these ozone-induced lesions may be attributable to the local dose of ozone reaching the affected area, the site-specific tissue susceptibility, or a combination of these factors. To determine the relative importance of each factor, we developed a three-dimensional (3-D) computational fluid dynamics (CFD) model of a 6-month-old rhesus monkey nasal passages in which the location of the different epithelial types was mapped [1]. Nasal geometry was obtained from magnetic resonance images (MRI) using computer-aided design software (Digital Data Viewer, www.compgeomco.com). Airflow simulations were performed for resting breathing (minute volume = 1.0 L/min) using a commercial CFD package (Fidap®, Fluent Inc., Lebanon, NH). Ozone uptake by the mucus lining was assumed to be proportional to the ozone concentration at the wall [2]. The simulations predicted a hotspot of ozone flux at the same location where neutrophilic rhinitis with epithelial necrosis and exfoliation was microscopically identified, namely at the dorsal aspect of the anterior maxilloturbinate. Other hotspots were also predicted in regions where lesions were not observed (e.g., in the olfactory epithelium) and in regions where other types of lesions were noted (e.g., anterior respiratory epithelium). These results suggest that ozone uptake in the nasal passages is strongly correlated to the airflow distribution and ozone concentration near the wall, but that tissue susceptibility also plays a key role.

References:

[1] – Three-Dimensional Mapping of Ozone-Induced Injury in the Nasal Airways of Monkeys Using Magnetic Resonance Imaging and Morphometric Techniques. Carey SA, Minard KR, Trease LL, Wagner JG, Garcia GJM, Ballinger CA, Kimbell JS, Plopper CG, Corley RA, Postlethwait EM, Harkema JR. Toxicologic Pathology 35, 27-40 (2007).
[2] – Three-dimensional simulations of reactive gas uptake in single airway bifurcations. Taylor AB, Borhan A, Ultman JS. Annals of Biomedical Engineering 35, 235-249 (2007).

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