Model for the deposition of fine and ultrafine aerosol particles in the rat lungs

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Rats are commonly used for studies on the health effects of aerosols. Since airways offer the main entranceway for particles into the organism, deposition models of inhaled particles are an important aspect for these studies (Anjilvil & Angharian, 1995, MPPD model, 1999). Here a model for man (Ferron et al., 1988) is adapted to the rat lung using structure analysis of lung and nasal cavity of rats (Yeh et al., 1979, Schreider & Raabe, 1981). Calculated particle deposition using this model is compared with results from the MPPD model, with experimental data for fine particles (aerodynamic diameters $d_a > 0.2 \, \mu m$: Raabe et al., 1988; and others) and recent data for ultrafine particles (volume equivalent diameter $d_e < 0.1 \, \mu m$: Takenaka et al., 2004) and nasal deposition data ($d_e < 0.21 \, \mu m$: Gerde et al., 1991) for volume equivalent diameters $d_e$ smaller than 0.2 $\mu m$.

Since considerable uncertainties are present in the model parameters, we used this model to investigate the sensitivity of total particle lung deposition on physiological and aerosol-specific parameters, namely nasal dimensions, mean size of the alveolar ducts, size of the lungs, respiration conditions, particle density and polydispersity of the aerosol particles. Standard respiration conditions are a tidal volume of 2.1 cm$^3$ and a respiration frequency of 102 min$^{-1}$ (Anjilvil & Asgharian, 1995) for a rat with body weight of 330 g. Spherical monodisperse particles have a density of 2 g cm$^{-3}$ as used in most animal studies.

Total deposition is shown in Figure 1 calculated with the present model, the MPPD model and experimental data from literature. Differences of more than 20% of the total deposition (Figure 1) are found for changes of:

- size of the nose for $d_e < 0.01 \, \mu m$,
- size of the alveolar ducts and sacs for $0.2 < d_a < 1.5 \, \mu m$,
- total lung volume for $0.02 < d_a < 1.5 \, \mu m$,
- most respiration conditions for $d_a < 3 \, \mu m$,
- particle density less than 0.5 for $d_e < 1.5 \, \mu m$ and for $d_e > 0.3 \, \mu m$,
- geometric standard deviation larger than 1.6.

The present model differs more than 20% with data calculated with the MPPD model for $0.2 < d_a < 1.5 \, \mu m$. On the other hand total deposition calculated for
different body weights corrected for changes in tidal volume and respiration frequency (Guyton, 1949) and resting conditions do not change more than 20% for all diameters. Experimental data in the nose (Gerde et al., 1991) were larger than the calculated total lung deposition for $d_e < 0.008 \, \text{mm}$.

Total deposition for $d_e < 0.03 \, \text{mm}$ and $0.03 < d_a < 2 \, \text{mm}$ are mainly influence of the deposition properties of the nose and of the alveolar ducts, respectively. These parameters can be used to optimize the present deposition model.

Figure 1. Total deposition of monodisperse aerosol particles in the rat lungs.

MPPDep (1999). Multiple-path Particle Deposition Model, MPPDep v1.11. the Chemical Industry Institute of Toxicology (CIIT), USA, and the National Institute of Public Health and the Environment (RIVM), the Netherlands.